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COMPARISON SIMULATION RESULTS OF THE COLLIMATOR APERTURE IN HEPS STORAGE RING*

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Abstract

The High Energy Photon Source (HEPS) is a 6 GeV diffraction-limited storage ring light source, which is under construction and planned to be in operation in 2025. To protect the sensitive elements from being damaged and reduce the radiation level of the site, collimators will be installed in the storage ring to localize the particle losses. The Touschek scattering is the main cause of particle losses during daily nominal operations. Based on the Elegant simulations, we evaluate the physical design of the collimators, especially analysis the collimator performance with different collimator apertures. The simulation results will be introduced in this paper.

INTRODUCTION

The High Energy Photon Source (HEPS) [1] is the first 4th-generation light source built in China, which had started constructing in 2019 at Huairou, Beijing, and is planned to be in operation in the late 2025. HEPS comprises three parts: a 6 GeV diffraction-limited storage ring with a circumference of 1360.4 m, a booster accelerating the electron from 500 MeV to 6 GeV, and a 500 MeV linac. The storage ring of HEPS consists of 48 hybrid-7-bend achromat (H-7BA) cells grouped in 24 super-periods, by which the beam natural emittance of 34.8 pm is achieved in the latest lattice design [2].

Due to various reasons, the high energy electrons in the beam deviate from the design orbit and finally collide on the accelerator components, which can cause serious damage to equipments. The synchrotron radiation released by the deviated electrons increases the radiation level of the site and is harmful to the human body. To secure the personal safety and ensure the proper operation of the facility, collimators will be installed in the storage ring to localize the particle losses. During the daily normal operations of HEPS, the main cause of the particle loss is the Touschek scattering effect. We use the elegant code [3, 4] to simulate the Touschek scattering process of the beam, and calculate the particle loss ratios at various locations with different collimator apertures. The design targets of the collimators are:

(1) over 70% lost particles are localized in the collimators;

(2) less than 20% particle losses take place in the straight sections;

(3) the decrease of Touschek lifetime is well controlled, around 30% or less.

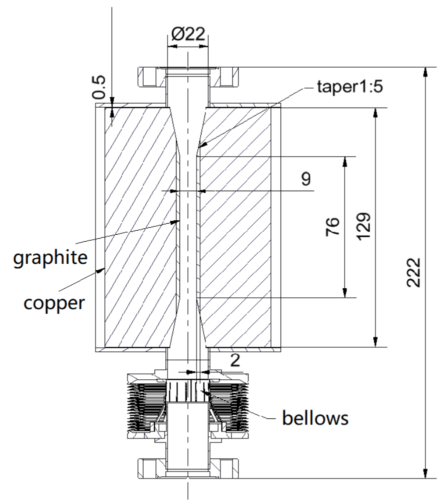

Figure 1: The sectional diagram of the collimator, in which the aperture is 4.5 mm.

Based on our previous research of an earlier version of lattice [5], the arrangement of collimators are determined to be 4 collimators evenly distributed on the storage ring, each of which is placed at the disperse bump in the upstream of high-beta straight section. The aperture of collimator is designed to be adjustable in a small range by moving the two copper blocks, and the structure is shown in Fig. 1. The physical apertures of the elements in lattice are listed in Table 1.

Table 1: The Physical Apertures of the Elements in the Lattice. The Masks Are Installed in the Upstream of Lambertson to Protect the Bellows in the Downstream from the Synchrotron Radiation

Positions	Aperture	Shape
arc regions	11mm*11mm	circular
high-beta sections	11mm*3.5mm	elliptical
low-beta sections	11mm*2.5mm	elliptical
Lambertson septum	5.24mm*2.5mm	elliptical
mask (high-beta section)	4.1mm*2.5mm	elliptical
mask (low-beta section)	3.9mm*2.5mm	elliptical

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BARE LATTICE

There are two separate simulations involved in determination of the effectiveness of the collimators. The first is using the "momentum_aperture" command in elegant to calculate the local momentum aperture (LMA) of the lattice, which is required for simulating the Touschek scattering and evaluating the variation of the Touschek lifetime. The second is using the "touschek_scatter" command to simulate the location distribution of Touschek scattering-induced beam losses. The simulation procedure consumes a lot of computing resources. To balance the accuracy of simulation results and the cost of CPU time, we set the number of tracking passes to 2000, and insert the "Tscatter" element after each BLG magnet and every 4 quadrupole magnets. The particle loss ratio at different positions are listed in Table 2. As we can see, the 4.6 mm aperture can achieve the design target for bare lattice. Over 71% scattered particles crash onto the collimators, less than 3% particles lost in low-beta and high beta sections, about 15% particles collide on the mask of Lambertson septum, and 11% particles lost in other places (mainly arc regions). The beam lifetime is calculated by adopting the "touschekLifetime" command in elegant, for which the parameters are set corresponding to the high-brightness mode of HEPS. For bare lattice without collimators, the beam lifetime is 1.5338 hours, while for the 4.6 mm aperture, the beam lifetime decreases about 31%.

Table 2: The Simulation Results of Particle Loss Ratio at Various Positions with Different Collimator Apertures, and the Corresponding Beam Lifetime Decrease Ratio. The Particle Losses on the Mask Are Excluded in the Statistics of Low-beta and High-beta Sections

Aperture	4.2 mm	4.6 mm	4.8 mm	5.0 mm
Collimator	85.41%	71.28%	60.69%	49.58%
Low-beta	0.72%	2.03%	3.42%	5.98%
High-beta	0.13%	0.80%	1.40%	2.52%
Mask	6.57%	14.83%	15.22%	16.40%
Others	7.17%	11.06%	19.28%	25.52%
Lifetime decrease	36.1%	30.73%	15.97%	0.45%

To test the convergence of the results, we plot the particle loss ratio for different tracking pass number, as shown in Fig. 2. It can be seen that, the particle loss ratio at the collimator decreases during the tracking from 600 to 800 passes, while the loss ratio at the mask increases simultaneously. The loss ratio in low-beta and high-beta sections remain almost unchanged with the increase of tracking passes. After 1000 passes of tracking, all ratios tend to be stable, thus we believe that the results after 2000 passes of beam tracking are reliable.

Figure 2: The particle loss ratio versus tracking pass number. (*top*) 4.2 mm aperture. (*bottom*) 4.6 mm aperture.

LATTICES WITH ERRORS

To evaluate the performance of collimators in the lattice with errors, we do simulations among a group of 100 random error seeds, with practical error introduction and dedicated orbit and optics corrections [6, 7]. Due to the enormous amount of calculation, it is impossible to simulate all of these seeds. We calculate the beam lifetime for every seeds, and pick up the lattices with maximal, medium and minimal beam lifetime to be three typical lattices, labelled as "MAX", "MED" and "MIN" lattice. Note that, to shorten the time of computation, at this step we only calculate the LMA in one super-periods and assuming LMA is periodic in the whole ring .

When performing simulations for the three typical lattices, we set the tracking passes to be 2000, and insert the "Tscatter" element after each BLG magnet and every 4 quadrupole magnets. The simulation results are listed in Tables 3 and 4. As shown in the table, the 4.0 mm aperture can satisfy the requirements for all the three typical lattices. Comparing with the results within bare lattice, a larger percent of particles lost in the straight sections, especially in the low-beta sections, while almost no particle collides on the mask.

Notably, we find that for the lattices with errors, the decrease of collimator aperture barely affect the lifetime of beams, as shown in Fig. 3. Since a smaller aperture yielding a higher particle loss ratio at collimators and has little effect on the lifetime of beams, a naive idea is to decrease the aperture until the lifetime of beams acutely changes. To investigate the critical value of aperture, we simulated a series of smaller aperture, and the results for the "MIN" lattice are plotted in Fig. 4 for an example. It is obvious that the beam lifetime has little change until the aperture decreases to about 3 mm. However, a latter calculation shows that the most stringent constraint on the aperture are not from

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the Touschek scattering, the impedance of collimators with aperture of 4.0 mm is already close to the coupled bunch instability threshold determined by the synchrotron radiation damping. By these facts, we set the nominal collimator aperture to be 4.0 mm. The minimal adjustable aperture is set to be 3.5 mm, which is determined by the constraint of machinery strength.

Table 3: The Particle Loss Ratio at Various Positions and the Beam Lifetime Decrease Ratio for the Three Typical Lattice, with the Aperture of Collimator Is 4.0 mm. Note That the Lifetime Listed in This Table Are Derived by Exactly Simulate the LMA of the Whole Ring

Lattice	MIN	MED	MAX
Collimator	75.97%	79.18%	79.84%
Low-beta	15.10%	12.89%	11.64%
High-beta	2.61%	2.13%	1.83%
Mask	0.00%	0.00%	0.01%
Others	6.33%	5.80%	6.67%
Lifetime decrease	0.47%	4.62%	2.44%

Table 4: The Simulation Results for the Three Typical Lattice with 4.2 mm Aperture

Lattice	MIN	MED	MAX
Collimator	68.46%	73.03%	72.65%
Low-beta	19.89%	16.69%	16.63%
High-beta	4.11%	3.29%	2.88%
Mask	0.00%	0.01%	0.01%
Others	7.54%	6.99%	7.82%
Lifetime decrease	0.22%	4.14%	1.47%

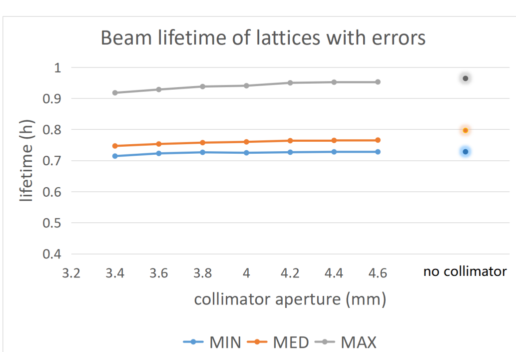

Figure 3: The beam lifetime with respect to different collimator apertures, for the lattices with errors.

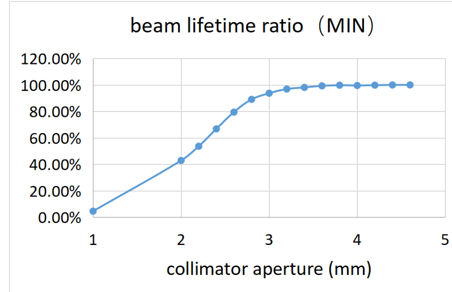

Figure 4: The ratio of beam lifetime with small collimator apertures to that without collimators, for the “MIN” lattice.

CONCLUSION

The design of the collimators on the storage ring of HEPS was determined based on the simulation results of the latest lattice, including both bare lattice and lattices with errors. We set 4 collimators evenly distributed on the storage ring, placed in the upstream of the high-beta section. The aperture of the collimator are determined by simulating the Touschek scattering process using the elegant code. For bare lattice, we found that the 4.6 mm aperture meets the requirement, while for the lattices with errors, the 4.0 mm aperture can achieve the design target. Overall consideration, the nominal collimator aperture was determined to be 4.0 mm, and the minimal aperture was set to 3.5 mm to remain the space of adjustment. In addition, these collimators are also used to localize the beam losses in cases of active or passive beam dumping, the related simulation results are displayed in [8].

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