BEAM LOSS SIMULATION AND RADIATION SHIELDING FOR TOP-OFF OPERATION OF HEFEI LIGHT SOURCE *

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Abstract

To better serve user experiments, the Hefei Light Source (HLS) is undergoing a series of upgrades to prepare for the top-off operation. To ensure radiation safety in the experimental hall, simulations under various system errors in the HLS storage ring are performed to get in-depth understanding of the nature of beam loss. To make the radiation shielding more effective, a beam scraper is used to decrease the aperture opening of the vacuum chamber, and additional shielding is installed around the scraper. Simulation and measurement results are reported in this paper.

INTRODUCTION

The Hefei Light Source (HLS) is composed of an 800 MeV linac, a transfer line, and an 800 MeV storage ring [1,2]. Since the energy of the linac is the same as that of the storage ring, the HLS basically has the ability to be operated in the so-called top-off mode. During top-off operation, injection of the electron beam into the storage ring occurs frequently, typically every few minutes per injection, to compensate the beam current reduction due to various loss mechanisms. This can significantly increases the integrated optical flux. Operating in top-off mode can also mitigates the thermal effect of the storage ring.

However, there are a number of factors that limits the machine to be operated in the top-off mode. Among these factors, the radiation safety is of great importance. Under present conditions, the HLS is operated in the traditional decay mode. There are three to four injections within 24 hours. People are forbidden to stay in the experimental hall during injection time for safety reasons. To operate the machine in top-off mode, the radiation shielding must be improved so that the experiment is not interrupted, and the users can remain at the hall.

Limited by the equipment layout and available spacing, additional shielding wall is unable to be installed along the whole ring. Thus, we developed a radiation shielding scheme with which most electrons are designed to be lost at a specific location. An additional lead wall installed around this location for effective shielding.

This local shielding scheme is simulated using the Accelerator Toolbox (AT) developed based on Matlab [3,4]. This paper reports the preliminary results of the simulation.

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AVAILABLE APERTURE

The Available aperture is defined to be the local acceptance, and is given by

$$A\left(s\right) = \frac{R(s)}{\sqrt{\beta(s)}}, \quad (1)$$

where $R(s)$ and $\beta(s)$ are the physical aperture and betatron function at the location s, respectively. Electrons with large oscillation amplitudes are most likely to be lost at the locations with minimum available aperture.

The available aperture of the HLS storage ring calculated using Eq. (1) is shown in Fig. 1. The figure shows that, the minimum available apertures in the horizontal direction are located in two long straight sections (SSs), including the injection SS and the SS in the opposite side of the injection SS. In the vertical direction, all four short SSs have minimum available aperture.To localize the beam loss, a beam scraper is installed in the injection SS shown as straight lines in Fig. 1. The aperture opening of the scraper is reduced to some extent so that the electrons are mostly lost at the location of the scraper when their betatron oscillation amplitudes are large enough.

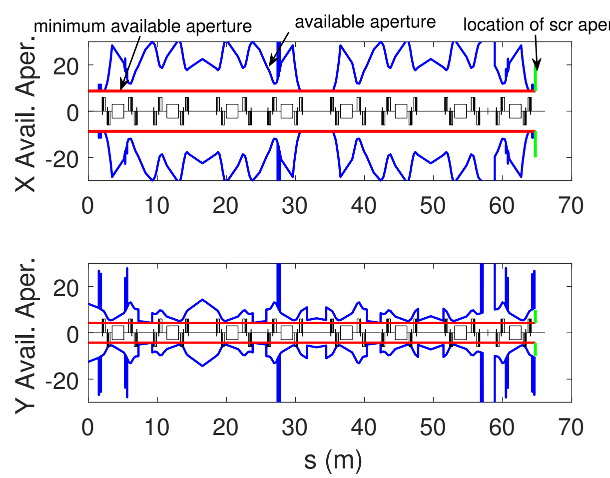

Figure 1: (color) The available aperture alone the HLS storage ring. (up) horizontal direction; (down) vertical direction.

ELECTRON TRACKING

Particle tracking using AT is performed to check the effectiveness of the scraper to blocking electrons with large oscillation amplitude. Only two scenarios, beam injection and dumping, are studied in this paper. The aperture opening

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of the scraper is reduced to [-0.050,0.030] m in the horizontal direction and [-0.008,0.008] m in the vertical direction, which leads to the smallest available aperture at the location of the scraper.

Tracking the Injected Electrons

Since people are allowed to stay in the experiment hall during the top-off operation, the electrons with large oscillating amplitudes in the injecting beam should be lost around the well shielded beam scraper area. Beam loss simulations are performed via particle tracking. In the simulations, electrons with different initial conditions in the injecting beam are tracked in the storage ring. The initial conditions of the electrons are varied between the limits shown in Table 1. The varying range in each axis is large enough to make sure that there are electrons lost during the simulations. Electrons are tracked in three planes of phase spaces, x and x′, y and y′, and x and dp/p, respectively.

Table 1: Initial Conditions of the Electrons

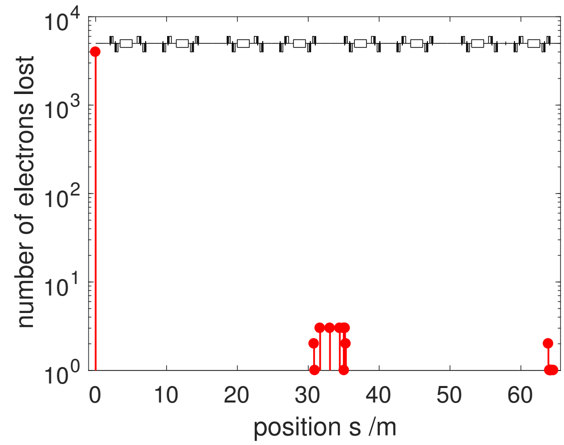
Items	Minimum/m	Maximum/m	Step/m
x	-2.95×10^{-2}	4.95×10^{-2}	7.90×10^{-4}
x′	-1.50×10^{-3}	1.50×10^{-3}	3.00×10^{-5}
y	-7.95×10^{-3}	7.95×10^{-3}	1.59×10^{-4}
y′	-1.50×10^{-3}	1.50×10^{-3}	3.00×10^{-5}
dp/p	-1.00×10^{-2}	1.00×10^{-2}	2.00×10^{-4}

The electrons are first tracked for one thousand turns in the storage ring using *ringpass*, one of the AT tracking methods usually used for tracking in storage rings. If there are electrons lost in the tracking, the lost electrons are then tracked using *linepass* — another AT tracking method mainly used for transfer lines, to figure out where the electrons get lost. The positions where the electrons get lost are recorded. Figure 2 shows the results of the simulations. It clearly indicates that the vast majority of electrons are lost in the scraper area, and the induced radiation should be well shield by the new installed shielding wall.

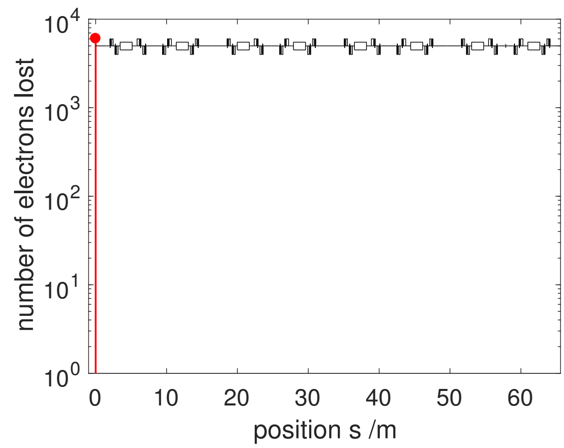
Electron Tracking During Beam Dumping

The electron beam in the HLS storage ring sometimes need to be dumped to allow people go inside of the storage ring hut. During beam dumping, the electrons are "killed" using one of the injection kicker. The kicker is located at 0.4 m upstream to the beam scraper. The kicker is magnetized using a half-sine wave current as shown in Fig. 3, the bottom width of the kicking waveform is about 1.3 μs . The revolution period of electrons in the storage ring is about 0.3 μs and electrons will be kicked three times each time the kicker fires. The ratio of the magnitudes of those three kicking is about 0.58 : 1.0 : 0.59.

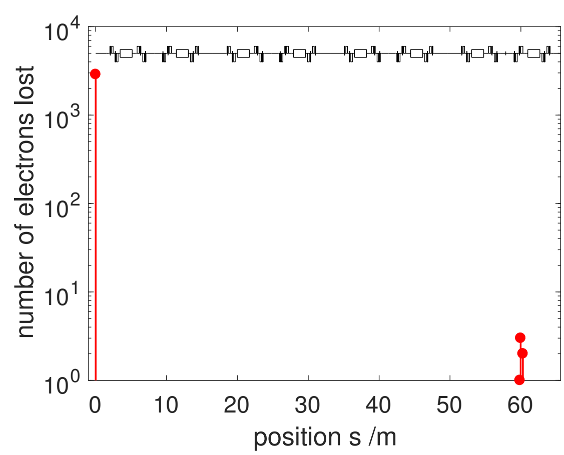
In the simulations, the maximum kicking angle is varied from 0.1 to 0.3 mrad, and the kicking angle of each kick are set according to the ratio given above. Under each set of kicking angles, the electrons are tracked 1000 turn in the storage ring. The results are plotted in Fig. 4, which also indicates the electrons mostly lost in the scraper area.



(a)



(b)



(c)

Figure 2: Electron lose under during injection. (a) Simulation in the x-x′ plane; (b) simulation in the y-y′ plane; (a) simulation in the x-dp/p plane.

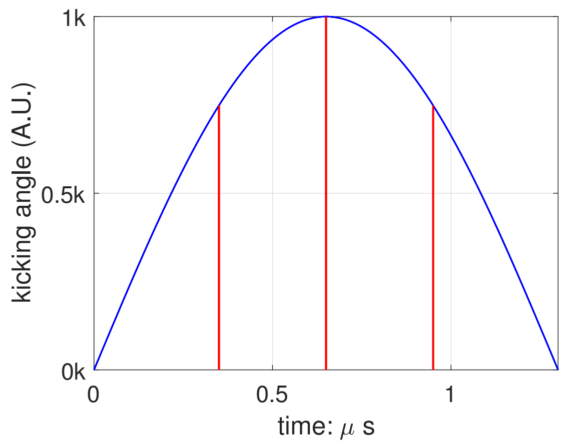
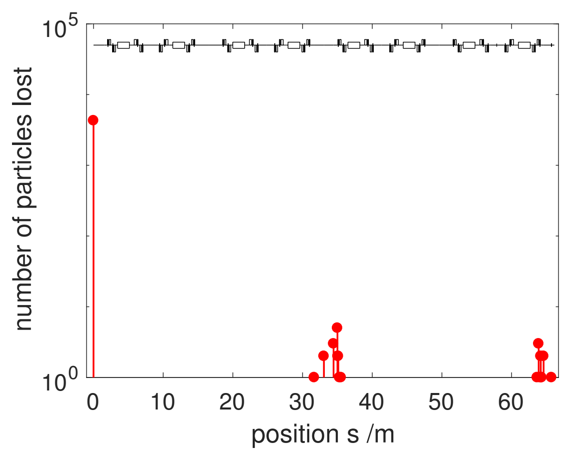


Figure 3: The kicking angles of a injection kicker.



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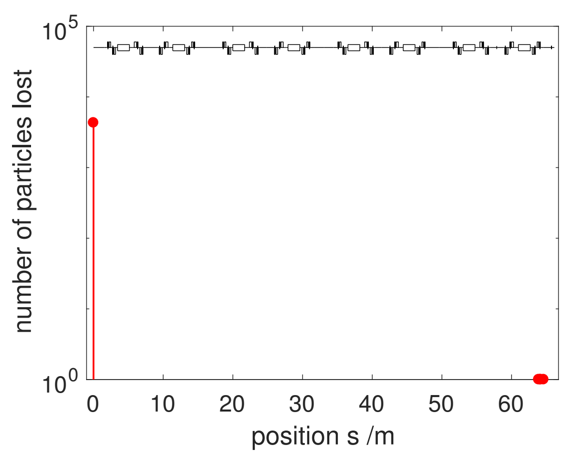
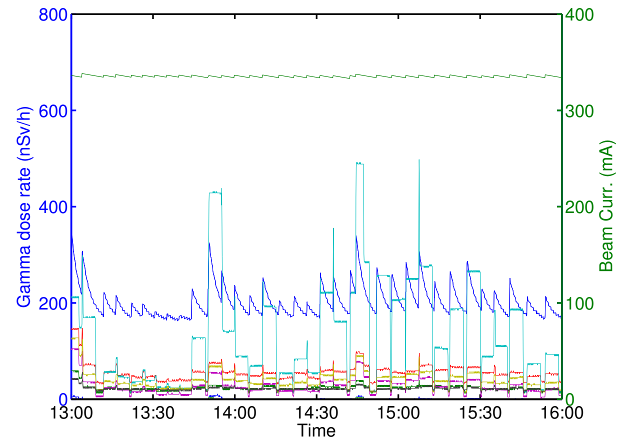


(b)

Figure 4: Electron loss with different kicker angles. (a) kicking angle equals 0.1 mrad; (b) kicking angle equals 0.3 mrad.

RADIATION DOSE RATE MEASUREMENT

The radiation dose rate is measured before and after installing the additional shielding wall around the beam scraper. The results , as shown in Fig. 5. indicate that shielding method is effective to reduce the injection induced radiation.



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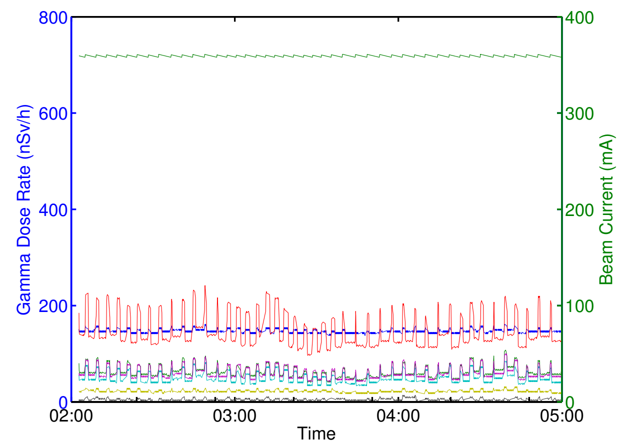

(b)

Figure 5: The measured radiation dose rate. (a) Before the additional shielding wall installed; (b) after the additional shielding wall installed

SUMMARY

Both simulations and measurements show that using a scrapper with proper opening and a shielding wall around it is effective to mitigate radiation during injection and beam dumping.

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