CALCULATION FOR THE RADIATION DOSE IN STORAGE RING HALL BASED ON MONTE CARLO METHOD*

Shunli Huang, Tianlong He, Tong Zhang, Shancai Zhang#
NSRL, University of Science and Technology of China, Hefei 230029, P. R. China

Abstract

Radiation dose assessment in synchrotron radiation facility is challenging due to the complexity and uncertainties of radiation source terms induced by high energy particle accelerator. Hefei light source (HLS) is the first dedicated synchrotron radiation light source in China. Radiation dose assessment for users at HLS Beam lines is highly concerned. This study presents the method calculating the radiation dose in storage ring hall under normal operation state, the simplified Monte Carlo calculation model was introduced in detail. We obtained the results of radiation dose distribution in HLS storage ring hall with using MCNP, which are in the same order of magnitude with the experimental results. It indicates that the method can be used to calculate the radiation dose level in storage ring hall, and it has certain guiding significance for the radiation protection.

INTRODUCTION

In normal operation, the electron beam in storage ring will decrease exponentially with respect to time [1]; the lost electron will eventually hit the wall of the vacuum tube. Since the electron energy is high, it's interaction with the wall of the tube is a cascade shower (shower) physical processes, it will produce shower electrons and secondary γ-rays, the part of γ-ray with higher energy will result in light-induced nuclear reactions and producing neutrons [2]; γ-rays and neutrons have strong penetration which constitute the mixed radiation field in the storage ring hall. We must strictly control the radiation dose level in the ring hall in order to reduce the radiation hazards to workers as possible, therefore, it is necessary to know the radiation dose ring in the central chamber to ensure that it is lower than the dose of radiation protection standards. The radiation dose is usually obtained by experimental measurements, we propose an approximation of beam loss model at HLS. Based on the approximation, MCNP is used to calculate the radiation dose distribution in the HLS storage ring hall. Comparing to the experimental results, the calculation results' difference is smaller than one order of magnitude.

RADIATION DOSE CALCULATION METHOD

Calculation Method

If the lost beam energy distribution, the amount of lost electrons and collision angle with the wall are known at any point on the storage ring, available-related programs such as MCNP and EGS can be used to calculate the radiation particles distribution outside the ring. MCNP can also directly calculate the radiation dose, EGS can indirectly calculate the radiation dose according to the related literature which give the relationship between the radiation dose and radiation particle fluence [3]. Assuming that the energy of lost electrons is E_i, the amount is K_i, the collision angle with the wall is α_i. then in the beam orbit plane, the radiation dose from the outside distance r_i of the ring and at the direction θ_i can be expressed as:

$$H = \sum_{i=0}^{N} H\left(K_i, E_i, \alpha_i, r_i, \theta_i\right) \tag{1}$$

Eq. 1 can calculate the radiation dose outside the ring anywhere.

If the simulation of the beam loss is in detail, it will result in a difficult calculation. Fortunately, according to the lattice structure and design parameters of the storage ring, the beam loss can be approximate to a certain degree. Thus, we just need establish a model for one position on the ring, the radiation dose can be obtained anywhere outside the ring.

Approximate Beam Loss

We introduce this simplified approximation beam loss in HLS storage ring with a circumference of about 66m and electron cyclotron frequency of 4.533MHz. It's designed to operate at up to 300mA stored beam current and 800MeV energy. The designed beam lifetime is 5.15hrs, touschek lifetime is 6.5hrs and vacuum life is 24.8hrs. Storage ring structure and beam loss position are shown in Fig. 1, 2 [4].

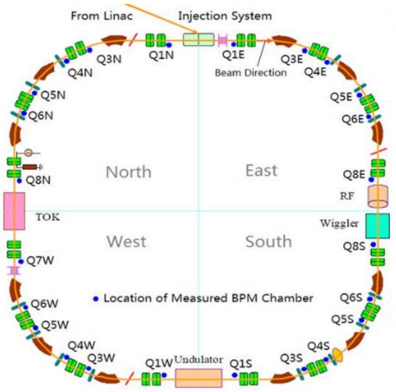

Figure 1: The structure of HLS storage ring.

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* Supported by National Natural Science Foundation of China (No. 21327901).
# Corresponding author (email: shancai@ustc.edu.cn)

Approximation of beam loss at HLS as follows:

1. As shown in Fig. 1: the equivalent radius is 10.5m.
2. The collision angle is assumed to be 2 degrees. In the calculation of the Radiation Dose, it include low energy electrons hitting the inner wall and high energy electrons hitting the outer wall.
3. Assuming that the energy of the lost electrons is approximately 800 MeV.
4. The electrons are considered equally lost in the 12 bend positions. A simple calculation can obtain that the average number of lost electrons in a position per second is1.17×10^6.
5. The number of lost electrons in the inner and outer sides of the same position is considered equal when calculating the Radiation Dose, and then 5.87×10^5 electrons are lost each side.

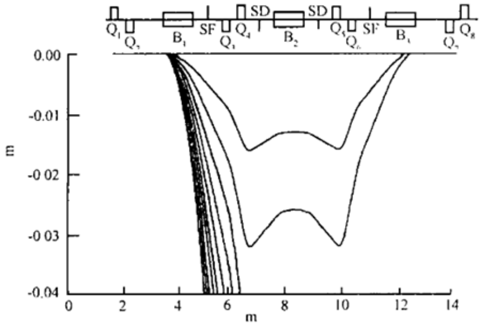


Figure 2: Schematic of beam loss position.

Dose Calculation

As shown in Fig. 3(a), point A and point B are symmetric about the beam orbit. After the above approximation, we can see that radiation dose outside of the position generated at point A is equal to the radiation dose inside of the position produced at point B. So the radiation dose of the position generated at point A is the sum of the inside produced at both point A and B. When the three parameters of Eq. 1(E_i, r_i, θ_i) are known, the radiation dose of the beam loss position in the direction of (r_i, θ_i) can be expressded as:

$$H_i\left(r_i,\theta_i\right)=H\left(r_i,\theta_i\right)+H_i\left(r_i,-\theta_i\right) \tag{2}$$

$H(r_i, \theta_i), H_i(r_i, -\theta_i)$ are respectively the radiation dose inside of the position in the direction of $(r_i, \theta_i), (r_i, -\theta_i)$.

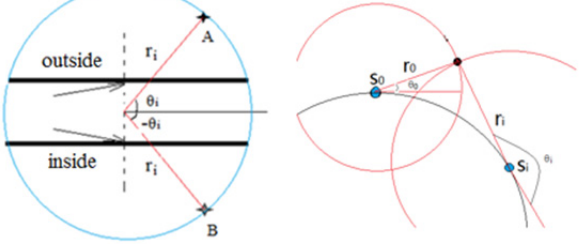
Fig. 3(b) is the calculation schematic of the generated radiation dose for any two beam loss position to a location outside the storage ring. For any point outside the storage ring, the r_i, θ_i with respect to the 12 beam loss point can be simply calculated. Given that the beam loss of each point is the same situation, therefore it can be used with one computational model. So the radiation dose of any point outside the ring can be expressed as:

$$\mathrm{H}=\sum_{i=1}^{12} H_i\left(r_{i,}\theta_i\right)=\sum_{i=1}^{12} H\left(r_{i,}\theta_i\right)+\sum_{i=1}^{12} H\left(r_i,-\theta_i\right) \tag{3}$$

Considering the actual situation, the lost number in the outer side is actually larger than the inner side. Therefore, Eq. 3 will be changed to Eq. 4.

$$\mathrm{H}=\sum_{i=1}^{12} H_i\left(r_i,\theta_i\right)=K_{in}\sum_{i=1}^{12} H\left(r_{i,}\theta_i\right)+K_{out}\sum_{i=1}^{12} H\left(r_i,-\theta_i\right) \tag{4}$$

K_{in}, K_{out} is respectively correction factor of the inside and outside. Their physical meaning is the ratio of the lost electrons of actual situation and approximate situation. For storage ring, it can be calculated that $K_{in} \approx 1.207, K_{out} \approx 0.793$.



(a) (b)

Figure 3: (a) Schematic of radiation dose calculation for a beamloss position. (b) Schematic of radiation dose calculation for storage ring.

CALCULATION MODEL

Monte Carlo N-Particle Transport Code (MCNP) is used primarily for the simulation of nuclear processes, such as fission, it has the capability to simulate particle interactions involving neutrons, photons, and electrons.

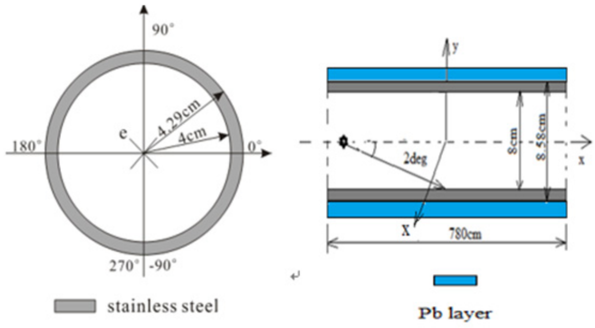
We use MCNP to simulate 800MeV electron collision process with the vacuum chamber in HLS storage ring. HLS storage ring's vacuum chamber is cylindrical, the cross-sectional schematic is shown in Fig. 5(a).The vacuum wall is made of stainless steel which density is $7.5\ g/cm^3$, and material composition and approximate value when calculating are shown in Table 1.

Table 1: Components of Materials that Constitute the Vacuum Chamber

Element	Content(%)	Approximation(%)
C	≤ 0.08	0.08
Si	≤ 1	1
Mn	≤ 2	2
P	≤ 0.045	0
S	≤ 0.03	0
Cr	18~20	18.5
Ni	8~10.8	8.42
Fe	70	70

The MCNP Calculation Model is shown in Fig. 5(b). 5cm thick layer of Pb is added outside the Vacuum tube. The electron source model is set to point source, The angel between the incident direction of source particles and x-axis is 2^0, the electron energy is set to 800 MeV, the tube length is set to 780cm, the inside diameter of the tube is 4cm and the tube wall thickness is 0.29 cm.

According to the approximation of beam loss, the distribution of radiation dose outside the ring has 12 cycles of symmetry. Two special directions of 900 and 750 with the ideal orbit are defined when calculating, as shown in Fig. 6, radiation dose of five positions (0.5 m, 1 m, 2 m, 4 m, 8 m) away from the ideal orbit of this two directions will be calculated.



(a) (b)

Figure 5: (a) Schematic diagram of the vacuum chamber cross section. (b) The calculation model of MCNP.

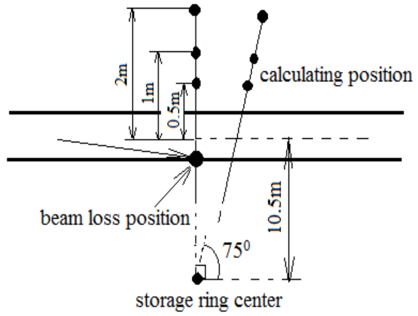


Figure 6: Schematic of calculating position.

RESULT OF CALCULATION

The radiation dose of neutron and γ-ray after calculation is shown in Table 2:

1. Radiation dose value in different directions at the same distance has big difference, and the closer distance is, the greater the difference have.
2. Since neutron and γ-ray distribution along each direction have a big difference. For example, γ-ray is mainly concentrated near the incident direction of electrons, and less in the opposite direction [5]. So it is resulted that neutron and γ-ray radiation dose values are quite different in different directions and not all the radiation dose decreases with the distance increasing in the same direction.
3. The radiation dose of neutron and gamma rays in the 90^0 direction is large, especially at the distance of 0.5 m.
4. Generally, users will stay 2 m or more away from the ring, at the distance of 2~4 m, the neutron radiation dose in the direction of 90^0 and 75^0 is 0.1~0.8 μSv/hr, the corresponding gamma rays radiation dose is 0.1~0.5 μSv/hr except 1.17 μSv/hr at (4 m, 75^0).

The radiation dose measurement result in Table 3 can be seen in reference [6]. In normal operation phase, the neutron radiation dose is 0.1~0.9 μSv/hr and the gamma rays radiation dose is 0.1~0.4 μSv/hr. It indicates that the dose calculated by MCNP and the measurement result are in the same order of magnitude.

Table 2: The Radiation Dose of Neutron and γ-ray(μSv/hr)

Radiation particle	position		r(m)			
			1	2	4	8
neutron	90^0	inside	1.45	0.41	0.12	0.04
		outside	1.22	0.32	0.09	0.03
		total	2.68	0.73	0.22	0.08
	75^0	inside	0.11	0.13	0.10	0.04
		outside	0.07	0.10	0.08	0.03
		total	0.18	0.23	0.17	0.08
photon	90^0	inside	0.41	0.19	0.04	0.08
		outside	0.64	0.26	0.04	0.03
		total	1.05	0.45	0.08	0.12
	75^0	inside	0.04	0.05	0.88	0.02
		outside	0.02	0.04	0.30	0.02
		total	0.06	0.09	1.17	0.04

Table 3: The Measurement Results (μSv/hr)

Radiation particle	r(m)	
	4	8
neutron	0.6-0.9	0.1-0.5
photon	0.3-0.4	0.1-0.3

It should be noted there are some errors between the approximate results in Table 2 and the actual results. It is assumed in our paper that beam is lost equally in 12 positions. Although the loss distribution is unequal, but for the normal operation of the storage ring, in general, the difference is not great.

CONCLUSION

In this paper, under beam loss approximation, we obtained the results of radiation dose distribution in HLS storage ring hall using MCNP(Monte Carlo N-Particle Transport code), which are in the same order of magnitude with the experimental results. It indicates that the approximate method can be used to calculate the radiation dose level in storage ring hall, and it has practical guiding significance for the radiation protection design. More work will be processed in future.

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