Theoretical analysis of BLM system for HLS Ⅱ *

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Abstract: Hefei Light Source (HLS) is being upgraded to HLS Ⅱ. Its emittance will be much lower than before, therefore the Touschek scattering will increase significantly and become the dominant factor of beam loss. So it is necessary to build a new beam loss monitoring (BLM) system that, in contrast to the old one, is able to obtain the quantity and position information of lost electrons. This information is useful in the commissioning, troubleshooting, and beam lifetime studying for HLS Ⅱ. This paper analyzes the distribution features of different kinds of lost electrons, introduces the operation parameters of the new machine and discusses how to choose proper monitoring positions. Based on these comprehensive analyses, a new BLM system for HLS Ⅱ is proposed.

Key words: storage ring, beam loss, beam lifetime, Touschek lifetime

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1 Introduction

For an electron storage ring, beam loss is inevitable during the running period. It reduces the beam current and shortens the beam lifetime. Hence, a BLM system is needed to evaluate the condition of beam loss and help researchers to optimize the parameters of the ring.

DESY built the first dedicated BLM system for the electron ring of HERA in 1993 [1]. There are 214 PIN-photodiodes beam loss monitors mounted on the inner side of the vacuum chamber along the ring. This system is used to monitor the position of heavy localised beam loss and thus realize a higher current with a stable lifetime. Cooperating with Tsinghua University, NSRL has developed the first BLM system for a storage ring in China. It was applied in the storage ring of HLS [2]. Its data acquisition system was developed by Tsinghua University, which can offer the intensity, distribution and time information of the beam loss in real-time [3, 4]. This BLM system is helpful for machine study and operation. Afterwards, BEPC Ⅱ and SSRF sequentially built their BLM systems, which also achieved good results [5, 6].

In HLS, we also applied a BLM system to study beam lifetime[7, 8]. We mounted monitors in pairs correspondingly on the inner side and the outer side of the vacuum chamber of the ring. Different signals from these two sides can help to distinguish the contribution of Touschek scattering or residual gas scattering to the beam lifetime.

HLS is now being upgraded to HLS Ⅱ. The beam parameters of the new ring are significantly different from those of the old one. In order to get higher synchrotron radiation brilliance, the emittance is much lower than before. This change will increase the probability of Touschek scattering and therefore the Touschek lifetime τ_T will be the dominant factor of the beam life. In this case, we are going to build a new BLM system and enhance its ability for Touschek scattering monitoring.

2 Three kinds of beam lifetime

The total beam lifetime τ can be mainly divided into Touschek lifetime τ_q, vacuum lifetime τ_v and quantum lifetime τ_T. Their relationship can be described as Eq. (1).

$$\frac{1}{\tau}=\frac{1}{\tau_q}+\frac{1}{\tau_v}+\frac{1}{\tau_T}. \quad (1)$$

These three kinds of beam lifetime are determined by three different causes, which may lead to different distributions of lost electrons. This means that the three causes can be distinguished by the different distributions of lost electrons.

Quantum lifetime τ_q: Density of the electrons in a bunch can be described by Gaussian distribution. If the electrons' momentum deviation exceeds the momentum acceptance, then they will be lost. After these electrons are lost, the quantum effect will inspire the other electrons to change their momentum so that the density of the electrons can keep Gaussian distribution. Inevitably,

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there are always a few electrons which exceed the momentum acceptance and get lost. The beam lifetime determined by this effect is named quantum lifetime. Because the Gaussian distribution is symmetrical, the lost electrons on different sides of the vacuum chamber will also be symmetrical.

Vacuum lifetime τ_v: Although the vacuum pressure can reach 10^{-10} Torr, there are still residual gas molecules in the storage ring chamber. If a high energy electron is scattered by these residual gas molecules, then its momentum may be changed. When the momentum deviation exceeds the momentum acceptance, it will sooner or later be lost. The beam lifetime determined by this effect is named vacuum lifetime. Because this effect always reduces the momentum of electrons, when these electrons pass the dipole magnet their deflection angles will be larger than those of the electrons with nominal momentum. So the residual gas scattering will be more likely to cause electrons to be lost on the inner side of the ring after they pass the dipole magnet.

Touschek lifetime τ_T: the transverse momentums of the electrons in the same bunch are different from each other. Since elastic scattering may occur among these electrons, their transverse momentum may be transferred into longitudinal momentum. If one electron's longitudinal momentum increases, then another electron's longitudinal momentum must decrease at the same time. When the longitudinal momentum deviation exceeds the momentum acceptance, both of these electrons will be lost [9]. The beam lifetime determined by this effect is named the Touschek lifetime. The electron that decreases longitudinal momentum will be more likely to be lost on the inner side of the ring after they pass the dipole magnet, while the other electron that increases longitudinal momentum will be more likely to be lost on the outer side of the ring.

3 Installing the detectors

The BLM system is mainly used to diagnose the vacuum leakage, so the detectors are mounted on the inner side of the ring only. But the above analysis shows that the distributions of lost electrons corresponding to three different kinds of beam lifetime are different. Therefore, we tried to build a new BLM system that can not only diagnose the vacuum leakage but also distinguish these three beam lifetimes' contribution to the total beam lifetime based on the electrons' distributions on different sides.

In the BLM system for HLS Ⅱ, we plan to mount detectors in pairs on the inner side and the outer side of the vacuum chamber in a horizontal direction, as shown in Fig. 1, and on the upper side and the lower side in a vertical direction, as shown in Fig. 2. This method of installing the detectors can provide us with a more comprehensive view of beam loss.

For example, Touschek scattering will make the electron loss on the inner side and the outer side of the ring equivalent, while the residual gas scattering will just make the electrons to be lost on the inner side of the ring. So the data of lost electrons on the outer side can represent the Touschek lifetime and the data of lost electrons on the inner side minus that on the outer side can represent the vacuum lifetime. Moreover, the detectors on the upper side and the lower side, which have not been taken into account in the HLS BLM system, will provide much more information of beam loss.

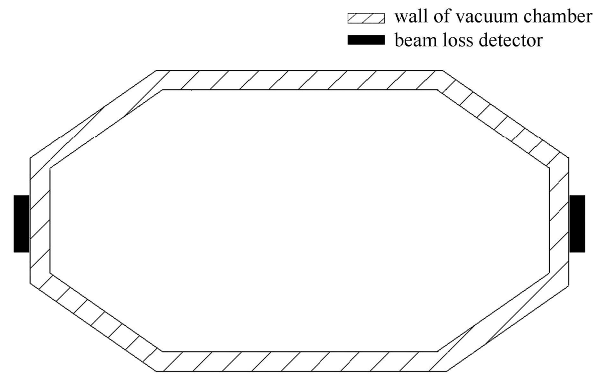

Fig. 1. Cross section of the vacuum chamber and the detectors in a horizontal direction.

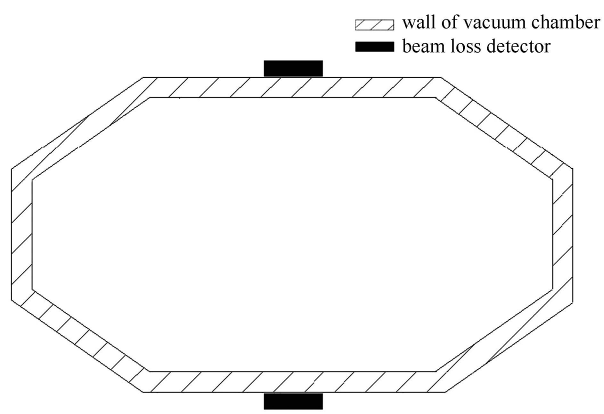

Fig. 2. Cross section of the vacuum chamber and the detectors in a vertical direction.

4 Monitoring position selection

4.1 Principle of choosing the monitoring positions

As the number of detectors is limited, we have to choose the most suitable locations along the ring as monitoring positions. To get high detection efficiency, we should choose where the beam loss rate is higher than other positions. To facilitate the study of beam lifetime, we should choose where the cause of the beam loss can be distinguished by the distribution of lost electrons.

When the deviation of the electron's trajectory is greater than the limitation of the vacuum chamber, this electron will hit on the vacuum chamber wall and be lost. The greater this deviation is, the more easily the electron will be lost. So we should choose those positions where the trajectory deviation is the greatest as monitoring positions.

The trajectory of the electron in horizontal direction and vertical direction can be described respectively by Eq. (2) and Eq. (3).

$$x=x_{\mathrm{osc}}+\delta\cdot D_x=\sqrt{a_x\cdot\beta_x}\cos\Phi_x+\delta\cdot D_x. \quad (2)$$

$$y=y_{\mathrm{osc}}=\sqrt{a_y\cdot\beta_y}\cos\Phi_y. \quad (3)$$

In Eq. (2), x_{osc} and $\delta\cdot D_x$, respectively, represent the horizontal betatron oscillation and dispersive trajectory of the electron. The horizontal oscillation Action a_x is constant for a certain electron. We can find that the larger Beta function β_x and dispersion function D_x are, the greater the trajectory deviation will be. This means that we should choose those positions where the β_x and D_x are largest as the horizontal monitoring positions. Similarly, from Eq. (3), we can find that the larger β_y is, the greater the amplitude of vertical oscillation will be. So we should choose those positions where the β_y is greatest as the vertical monitoring positions.

4.2 Monitoring positions of HLS Ⅱ

In order to find the most suitable positions for the HLS Ⅱ BLM system by the principles mentioned above，it is necessary to study the lattice of HLS Ⅱ. The Lattice is DBA structure in HLS Ⅱ. There are four symmetrical DBA cells in the ring of HLS Ⅱ. In each cell, there are two dipole magnets, four horizontal focusing quadrupole magnets and four vertical focusing quadrupole magnets. By adjusting the magnetic field intensity of the DBA cells, HLS Ⅱ can run in two modes. One is a standard mode, in which the dispersion along the long straight section is zero (see Fig. 3). The other is a low-emittance mode, in which the dispersion along the long straight section is nonzero (see Fig. 4). We will discuss these two modes in the following sections.

According to the Lattice of HLS Ⅱ, we have calculated the Twiss parameters and the dispersion function of these two modes, respectively. The results are shown, respectively, in Fig. 3 and Fig. 4.

By combining the distribution of the Twiss parameters and the dispersion function in these two modes, we can find that β_x and D_x may reach their maximum values before each horizontal focusing quadrupole magnets, and β_y reaches its maximum value before each of the vertical focusing quadrupole magnets. This means that electrons will be more easily lost before each of the horizontal focusing quadrupole magnets in a horizontal direction and each of the vertical focusing quadrupole magnets in a vertical direction.

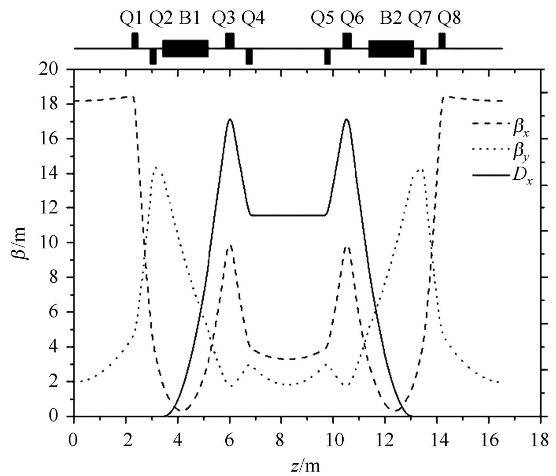

Fig. 3. Beta and dispersion function of the standard mode.

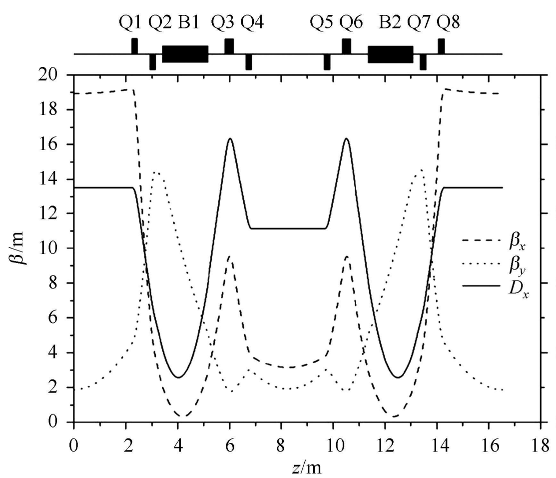

Fig. 4. Beta and dispersion function of the low-emittance mode.

Based on the comprehensive analysis given above, we chose those positions before the horizontal focusing quadrupole magnets (named Q1, Q3, Q6, Q8) as the horizontal monitoring positions and those positions before the vertical focusing quadrupole magnets (named Q2, Q4, Q5, Q7) as the vertical monitoring positions for the HLS Ⅱ BLM system. All of the monitoring positions along the ring are shown in Fig. 5. The detectors are mounted in pairs in a horizontal direction, as shown in Fig. 1, at positions of H_1 to H_16, and in a vertical direction, as shown in Fig. 2, at positions of V_1 to V_16.

4.3 Final adjustment of the monitoring positions

Since there are many other types of equipment installed along the ring, there may not be enough space for us to mount the detector at the exact position we have chosen above. Therefore, we have to adjust the monitoring position according to the actual conditions. The distribution of lost electrons near the maximum point of trajectory deviation can help us to decide how to choose the new monitoring position.

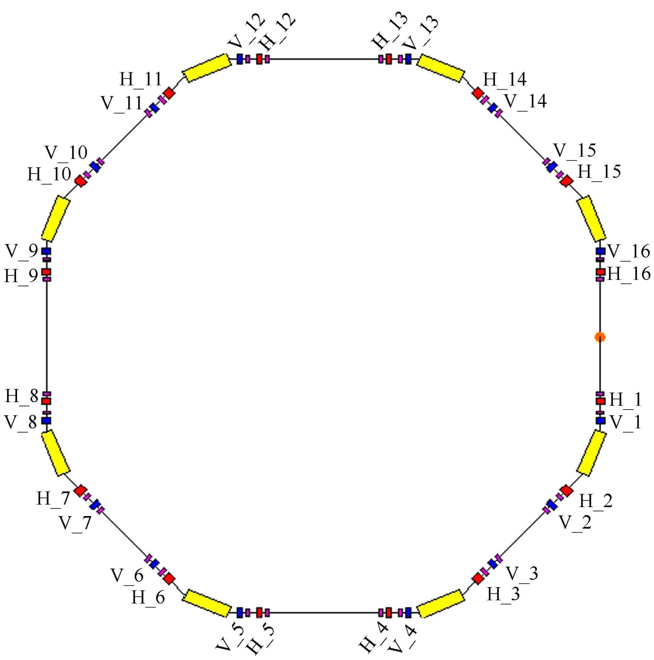

Fig. 5. (color online) Monitoring positions along the ring of HLS Ⅱ.

For example, in the standard mode, the trajectory of the electron with 1% to 10% momentum deviation is shown as Fig. 6. We can see from the figure that the maximum momentum deviation, which is restricted by the size of the vacuum chamber, is about 3%. If the momentum deviation is larger than 3%, then the electron will hit on the wall of vacuum chamber and become lost when it passes the dipole magnets because of excessive deflexion. The larger the momentum deviation is, the more the electron loss position will move backward to the opposite direction of the beam. There will be a few lost electrons after the maximum point of trajectory deviation. So we should adjust the monitoring position to those places before, but not after, the maximum point of trajectory deviation if necessary.

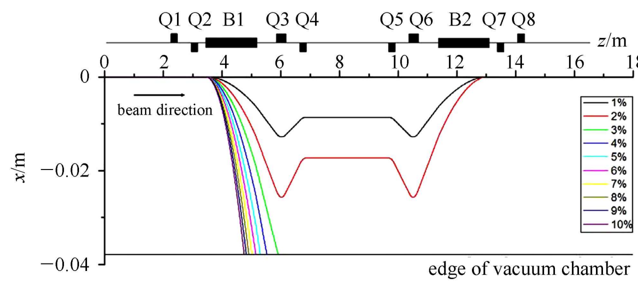

Fig. 6. (color online) Trajectory of the electron in horizontal direction with 1% to 10% momentum deviation.

5 Conclusion

In this paper we have discussed three kinds of beam loss and the distribution of lost electrons on different sides of vacuum chamber. According to these discussions, we plan to mount detectors in pairs on the inner side and the outer side, as well as the upper side and the lower side of the vacuum chamber. This method of installing the detectors can provide a more comprehensive view of beam loss, which is very useful in beam lifetime study. The monitoring positions have been chosen for HLS Ⅱ based on comprehensive analysis of Twiss parameters, dispersion function, and the trajectory of the electrons. The hardware and software for this new BLM system is being developed. This will play an important role in commissioning, troubleshooting, and study of the beam lifetime of the new ring.

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