A NEW THEORETICAL DESIGN OF BLM SYSTEM FOR HLS II*

Chen Yukai, Li Yuxiong, Li Weimin, Li Juexin, He Lijuan, National Synchrotron Radiation Laboratory of University of Science and Technology of China, Anhui, P.R.China

Abstract

Beam loss monitoring (BLM) system has been commonly used to detect the vacuum leakage. The existing BLM system for Hefei Light Source (HLS) was built in 2000. It played an important role in analyzing beam loss distribution and regulating the machine operation parameters [1, 2]. Recently, HLS is being upgraded to HLS II. The emittance will be decreased to increase the brilliance of synchrotron radiation. The Touschek lifetime will be much shorter than before, and dominate the total beam lifetime. It is necessary to redesign the BLM system for HLS II. The most important part of this work is to find a better method of monitoring Touschek lifetime by BLM system while keeping its general functions. According to the results of our research, a preliminary theoretical design for the new BLM system is proposed in this paper. This new system will play an important role in the storage ring commissioning, troubleshooting, and beam lifetime studying.

INTRODUCTION

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

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

Since τ_q is much longer than τ_T and τ_v, normally it can be neglected. We pay more attention to τ_T and τ_v in our work.

The BLM system was first used for monitoring the beam loss caused by residual gas scattering by DESY [3]. In phase II project of HLS, researchers have applied BLM system to beam life study [2]. HLS is now upgrading to HLS II. The magnet lattice of HLS II will be changed from TBA to DBA. The emittance will be much lower than before, and the Touschek lifetime τ_T reduces and becomes the dominant factor of the beam life. To match the new situation, We are going to build a new BLM system and enhance its functions of Touschek scattering detecting.

It has been known that the electron's transverse momentum can translate into longitudinal momentum by Touschek scattering. When an electron's longitudinal momentum increases, there must be another electron's longitudinal momentum decreases. Once the momentum variation exceeds the momentum acceptance of the ring, these two electrons will respectively lose in opposite horizontal direction. So we can obtain information about the Touschek lifetime by simultaneously detecting the electrons on two horizontal side of the vacuum chamber. Therefore the BLM system can be not only used to monitor the vacuum leak but also to obtain information about the Touschek lifetime on some level.

DETECTING POSITIONS FOR THE BLM SYSTEM

Principle of Detecting Position Selecting

To make the beam loss monitoring more effectively, it is important to select appropriate monitoring positions. These positions should satisfy the following requirements:

- Beam loss ratios should be higher than other positions, so that the detector can catch clear signals.
- Beam loss should be able to effectively reflect the overall situation of beam loss.
- Beam loss should be able to reflect the difference between the lost electrons produced by residual gas scattering and those by Touschek scattering.
- Detecting positions should be relatively well-distributed on the ring.

The Lattice Structure of HLS II

The Lattice structure of HLS II is DBA. In each DBA cell, two bend magnets make the electron beam bending 90 degrees. HLS II can run in standard mode (achromatic mode, whose dispersion along the long straight section is zero) and low-emittance mode (distributed dispersion mode, whose dispersion along the long straight section is nonzero).

The Twiss parameters and dispersion function of two modes in one DBA cell are respectively showed in Fig. 1 and Fig. 2. The distribution of Twiss parameters can be used to determine the detecting position.

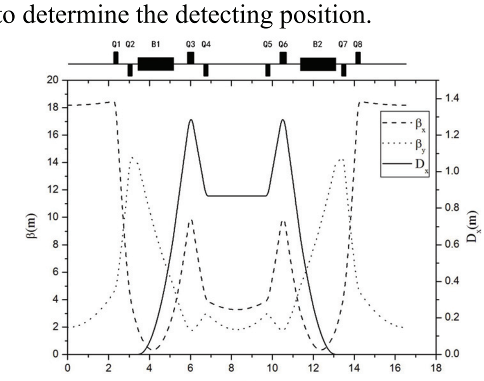

Figure 1: β and dispersion function of standard mode.

*Work supported by NSFC (11175180 and 11175182)
ykchen@mail.ustc.edu.cn

ISBN 978-3-95450-122-9

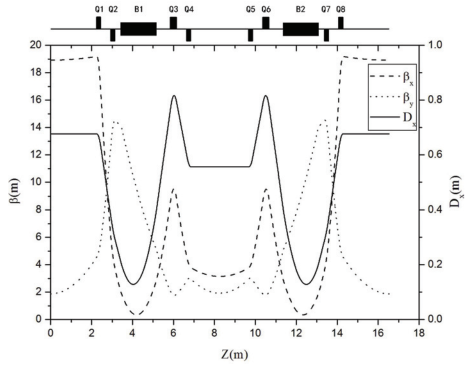

Figure 2: β and dispersion function of low-emittance mode.

Horizontal Detecting Position

Both gas scattering and Touschek scattering can change the longitudinal momentum of the electrons and make them deviate from the nominal orbit. Once the deviation exceeds the aperture of the vacuum chamber, the electrons will be lost. Residual gas scattering will just decrease the longitudinal momentum of the beam electrons, so the electrons usually lose on the inner side of the ring. Touschek scattering will decreases one electron's longitudinal momentum and meanwhile increases that of another electron, so electrons lose both on the inner and outer side of the ring.

Based on the storage ring physics theory, ignoring the higher order terms, relationship of the deviation of electron orbit and the momentum difference can be described by Eq. 2:

$$x_\varepsilon(z) = \delta \cdot D(z)\,. \tag{2}$$

Where $\chi_\varepsilon(z)$ is the deviation of the electron orbit at point z, δ is the momentum difference, and D(z) is the dispersion function.

When HLS II run in standard mode, the deviation of electron orbit in one DBA cell is as Fig. 3. If δ is more than 3%, the $\chi_\varepsilon(z)$ will be bigger than the aperture of the vacuum chamber at the next dispersion maxima, and the electron may lose. Combine the situation of low-emittance mode, the places before horizontal focusing quadrupoles Q1, Q3, Q6, and Q8 will be selected to be horizontal detecting positions in our BLM system.

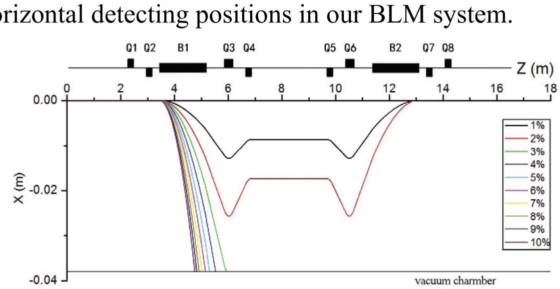

Figure 3: Deviation of the electron orbit with momentum difference from 1% to 10%.

Vertical Detecting Position

We also consider detecting the beam loss in the vertical direction. When gas scattering or Touschek scattering happens, the transverse oscillation momentum in the vertical direction may increase. In the vertical direction, the deviation of the electron orbit is mostly transverse oscillation. The relationship between the amplitude of this oscillation and the β function can be described by Eq. 3:

$$y_\beta(z)_{\max} = \sqrt{a \cdot \beta_y(z)}\,. \tag{3}$$

Where $y_\beta(z)_{\max}$ is the maximum deviation of the electron orbit at point z, $\beta_y(z)$ is the value of β function at point z, and a is the transverse oscillation Action of the electron. When particles scattering happen, the value of a may increase if the transverse oscillation of electron become more intense. Once the transverse oscillation momentum increases enough and make the amplitude of this oscillation bigger than the aperture's restriction, the electron may lose on the upper side or the downer side of the vacuum chamber. The larger the β_y function is, the more easily the beam electron will lose. From Fig. 1 and Fig. 2, we can find that β_y get the maximum value at the positions near vertical focusing quadrupoles Q2 and Q7, where the electrons loss on the vertical side will most likely happen. So the places before Q2 and Q7 are selected to be vertical detecting positions.

MONTE-CARLO SIMULATION OF THE SHOWER ELECTRONS

When the lost electrons transport in the wall of vacuum chamber, they will produce a mass of secondary shower electrons. We use the Monte-Carlo code EGSnrc [4] to simulate this process and calculate the distribution of the shower electrons outside the vacuum chamber. Calculation conditions include:

- The Cross-section of the vacuum chamber is an octagonal annular tube showed in Fig. 4; its material is 316L stainless steel.
- The lost electron's initial kinetic energy is 800Mev.
- Lost electrons impact on side A of the vacuum chamber at a small angle of 2 degrees deviating the direction of the beam, the loss occurs at (y,z)=(0,0).

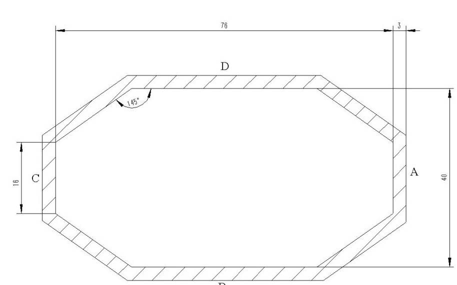

Figure 4: Cross-section of the vacuum chamber.

Distribution of the Shower Electrons on Side A of the Vacuum Chamber

We have got the distribution of the shower electrons on side A of the vacuum chamber by calculation (See Fig. 5).

- There is a relatively sharp peak of the distribution among the shower electrons, every lost electron can produce about 3 shower electrons per cm^2 at that point.
- The peak is 4.5cm behind the impact point. This is an important reference for choosing installation positions where the detector can get maximum signal.

The above results show that the shower electrons concentrate in a specific small area. The shower electrons carry with obvious position message. Base on this characteristic, the shower electrons can be used to orientate the lost electrons.

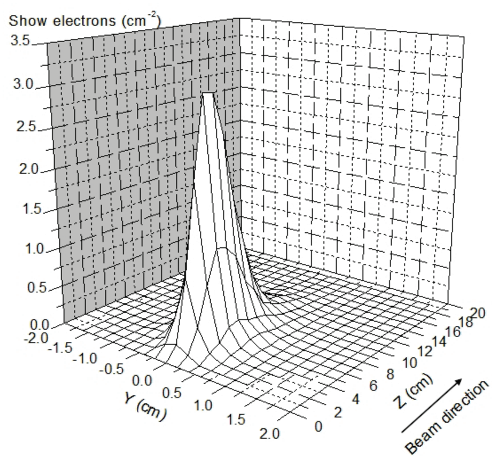

Figure 5: Distribution of the shower electrons on the side A.

Distribution Shower Electrons on Different Sides Around the Vacuum Chamber

When the lost electron is on side A, the distribution along the beam direction of the shower electrons on side A, B, C, and D is showed in Fig. 6.

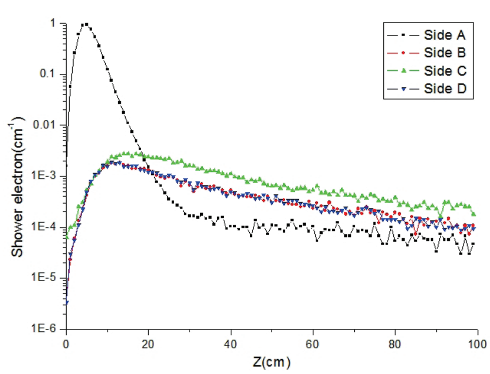

Figure 6: The distribution of the shower electrons on the side A, B, C, and D.

We find that the distribution of shower electrons on side A is more concentrated than that on side B, C, or D. The quantity of shower electrons on side B, C, or D is about three orders of magnitude less than that on side A. That means we can ignore the shower electrons produced by the lost electron on the sides except the incident side.

CONCLUSION

- The places before Q1, Q3, Q6, or Q8 will be selected to be horizontal detecting positions in our BLM system, and the places before Q2 and Q7 are selected to be vertical detecting positions. The detectors will be used in pairs (fixed on opposite sides of the vacuum chamber in horizontal or vertical direction) at each selected position.
- In the storage ring of HLS II, shower electrons produced by the lost electrons carry with obvious position message. The shower electrons are centralized and have a sharp peak in distribution, so that we can obtain information about the position and the quantity of the lost electrons by monitoring the shower electrons.
- When the electrons lose on a certain side of the vacuum chamber, there will be shower electrons all around the vacuum chamber because of reflection. But the shower electrons on the other sides of the vacuum chamber are about three orders of magnitude less than that on incident side. So the quantity of shower electrons on a certain side of the vacuum chamber is mostly determined by the quantity of lost electrons on this side.

REFERENCES

[1] Yuxiong L, Yonggang C, Weimin L, et al. The beam loss monitoring system for HLS storage ring. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2001, 467: 80-83.

[2] Li Yuxiong, et al., "The radiation measurement applied to beam lifetime study on the synchrotron radiation facilities", Nucl. Instr. and Meth. A 505 (2003) 366-369.

[3] W. Bialowons, F. Ridoutt, and K. Wittenburg, "Electron beam loss monitors for HERA," in Fourth European Particle Accelerator Conference (EPAC94), vol. 2, p. 1628,World Scientific, 1994.

[4] I. Kawrakow and D.W.O. Rogers, "The EGSnrc Code System: Monte Carlo Simulation of Electron and Photon Transport", NRCC Report PIRS-701, Sept. 2006.

ISBN 978-3-95450-122-9