BEAM LIFETIME ANALYSIS OF THE HLS-II STORAGE RING*

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Abstract

Beam lifetime is one of the important parameters of electron storage rings, which can describe the particle loss rate quantitatively and is restrict by quantum lifetime, beam-gas scattering and Touschek effect. The upgrade project of Hefei light source, named HLS-II, has greatly improved the performance of the light source. The beam lifetime has been maintained at more than 5 hours. In this paper, a combined analysis method is derived by the analysis of the beam lifetime, and the method is applied to the HLS-II storage ring. The experimental results show that this method is simple and reliable for the analysis of the Touschek lifetime and beam-gas scattering lifetime.

INTRODUCTION

The Hefei Light Source (HLS) was a second generation synchrotron radiation light source operated in the VUV to soft X-ray range with natural emittance of 166 nm•rad at electron beam energy of 800 MeV. After the upgrade, the performance of the almost brand new machine has been greatly enhanced. A new linac has been constructed with the capability of raising beam energy up to 800 MeV, which is the same energy of the beam in the storage ring. Therefore a full energy injection can be realized for the beam injection into the storage ring. A lower emittance of 38 nm•rad has been obtained with strong focusing quadrupoles in a 4×DBA lattice structure. Some critical parameters of HLS-II are listed in Table 1 [1].

Table 1: Main Parameters of the HLS-II Storage Ring

Beam energy [MeV]	800
Beam current [mA]	300
Natural emittance [nm•rad]	38
Transverse tune	4.4447/2.3597
RF Frequency [MHz]	204
Harmonic number	45
Natural energy spread (rms)	0.00047
Number of IDs	5
Operation Mode	Decay
Beam lifetime [hours]	8

Beam lifetime is a significant factor that decides the high performance operation time of the beam in a storage ring. There main factors can limite the beam lifetime, which are quantum lifetime, beam-gas scattering and Touschek effect. Because of the upgrade, the emittance is greatly decreased from 166 nm•rad to 38 nm•rad. The influence to the beam lifetime is increased with the decrease of the beam size especially for the Touschek effect. An overall analysis of the beam lifetime is a necessary work for the stable operation of the light source in a long time.

In this paper, a combined method for beam lifetime analysis is introduced and the experimental results are presented in detail.

COMBINATION ANALYSIS METHOD

The beam lifetime is an important parameter of storage rings, which can affect the operation of the storage ring. Beam lifetime can be expressed as follows [2].

$$I = I_0 e^{-\frac{t}{\tau}} \tag{1}$$

where I is the beam current at the t moment, I_0 is the beam current at the initial time, τ is the beam lifetime.

There are many factors that affect the beam lifetime, such as quantum excitation, gas scattering and Touschek effect. Due to the size of the vacuum chamber is much larger than the size of the electron beam in the HLS-II electron storage ring, the beam loss caused by quantum effect can be neglected compared with the total beam loss. The HLS-II beam lifetime is determined mainly by the Touschek effect and the beam-gas scattering as in

$$\frac{1}{\tau} = \frac{1}{\tau_{\mathrm{t}}} + \frac{1}{\tau_v} \tag{2}$$

where τ_{t} is the Touschek lifetime, τ_v is the beam-gas scattering lifetime. Although there are many methods to analyze Touschek life and vacuum life, but these methods have some limitations for the beam lifetime analysis during operation.

If the electrons number of per bunch is equal in the storage ring, the single bunch current is I_b, the Touschek lifetime is inversely proportional to I_b as in

$$I_b \tau_t = c \tag{3}$$

where τ_t denotes Touschek lifetime, c is the the proportionality constant [2, 3].

The beam-gas scattering lifetime is caused by the collision between the beam electrons and the residual gas molecules. The beam-gas scattering lifetime τ_v is inversely proportional to the gas density as in

$$\tau_v P = b \tag{4}$$

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where τ_v denotes beam-gas scattering lifetime, P is the gas density, b is the proportionality constant [3, 4].

According to the formula (1), the beam lifetime at t_1 and t_2 moments can be expressed as

$$\begin{cases} \frac{1}{\tau(t_1)} = \frac{1}{\tau_t(t_1)} + \frac{1}{\tau_v(t_1)} \\ \frac{1}{\tau(t_2)} = \frac{1}{\tau_t(t_2)} + \frac{1}{\tau_v(t_2)} \end{cases} \quad (5)$$

If you do not consider the gas analytic effect, from formula (3), (4) and (5) available:

$$\begin{cases} \frac{1}{\tau(t_1)} = \frac{I_{b1}}{c} + \frac{P_1}{b} \\ \frac{1}{\tau(t_2)} = \frac{I_{b2}}{c} + \frac{P_2}{b} \end{cases} \quad (6)$$

where I_{b1} and I_{b2}represent the single bunch current in the storage ring at t_1 and t_2 moments, $I_{b1} = B_1/n$, $I_{b2} = B_2/n$, B_1 and B_2 represent the current at t_1 and t_2 moments, n is the number of bunches of storage rings, P_1 and P_2 represent the storage ring vacuum pressure at t_1 and t_2 moments. By formula (6) can get the constant c and b, according to the constant c and b can calculate the Touschek lifetime and beam-gas scattering lifetime.

HLS-II BEAM LIFETIME ANALYSIS

In order to understand the Touschek lifetime and beam-gas scattering lifetime of the HLS-II storage ring, we take a period of operation data to analyze the beam lifetime, which can be seen in Fig.1. During this period, the storage ring beam is filled evenly with 35 bunches.

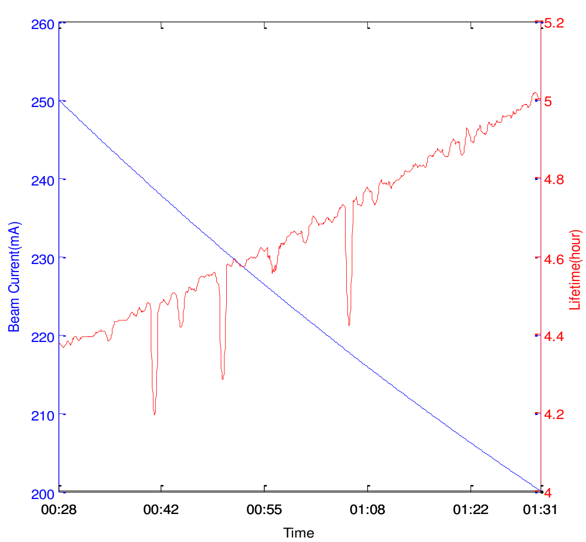

Figure 1: Beam current and lifetime in decay mode.

We record the values of the beam current, lifetime and average vacuum pressure value of this period with the sampling frequency of 0.5Hz. Because of the slight fluctuation of the beam lifetime and vacuum pressure, we linearly fit the beam lifetime and vacuum pressure. The fitting results are shown in Fig. 2 and 3.

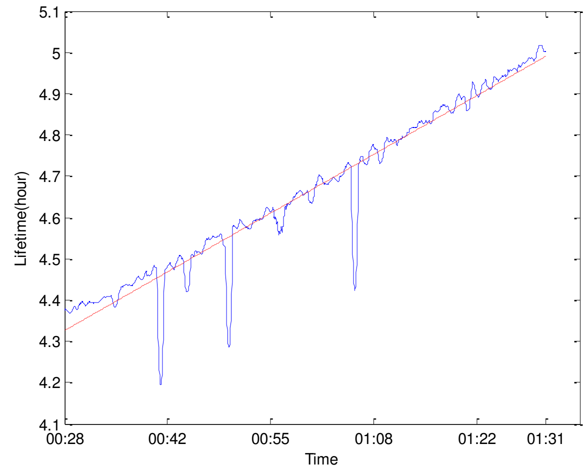

Figure 2: The fitting result of beam lifetime.

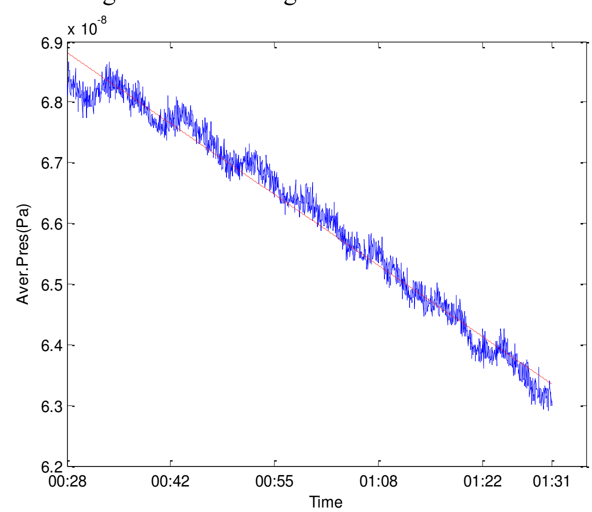

Figure 3: The fitting result of vacuum pressure.

So that we had a group of beam current, lifetime and average vacuum pressure data to take the fitting data. We take the 2 adjacent columns of data using formula (6) to get a series of the constant c and b. we linearly fit the constant c and b. The fitting results of the constant c and b are shown in Fig. 4 and 5.

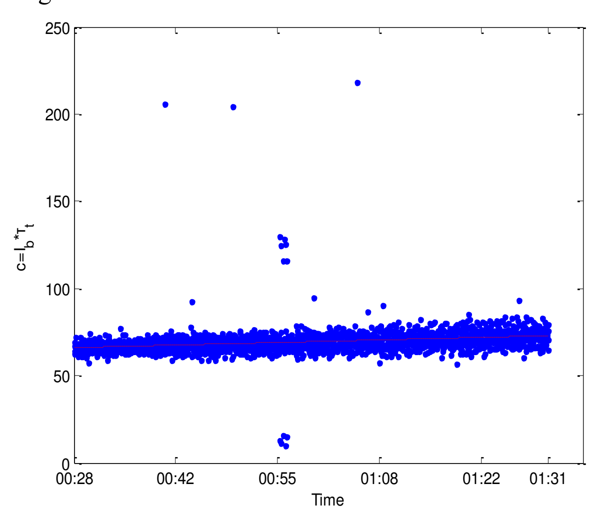

Figure 4: The fitting result of constant c.

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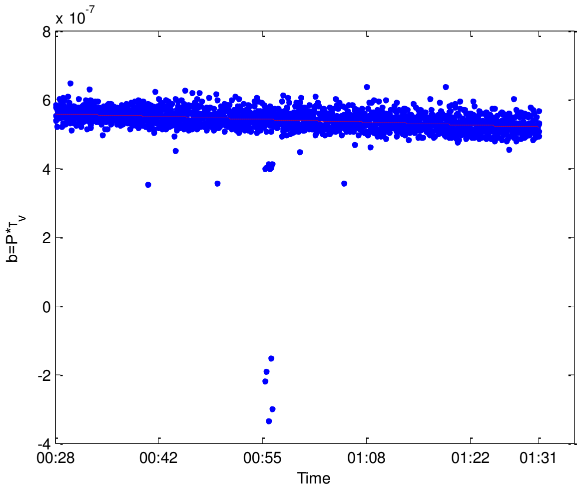

Figure 5: The fitting result of constant *b*.

The fitting curve in Fig. 4 approximates a horizontal line, which indicates that c is a constant. According to the fitting results, the c value is about 69.5. The results show that our calculation agrees with the formula (3). The fitting curve in Fig. 5 approximates a horizontal line, which indicates that b is a constant too. According to the fitting results, the b value is about 5.385e-7. The results show that our calculation agrees with the formula (4).

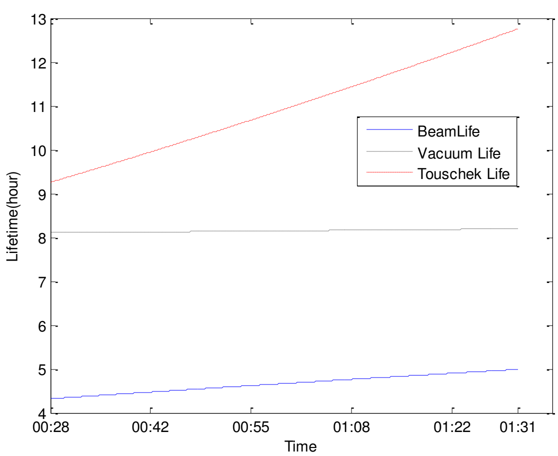

Figure 6: Calculated Touschek lifetime, beam-gas scattering lifetime and beam lifetime.

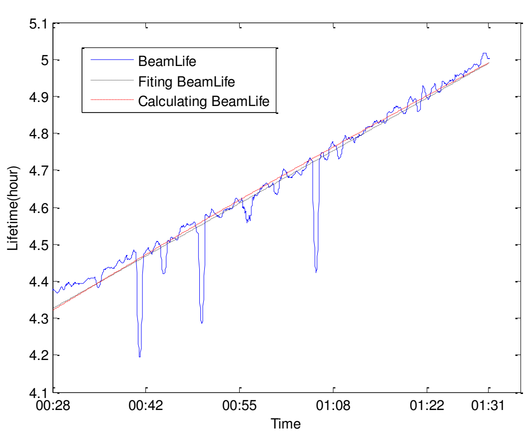

Figure 7: Beam lifetime, fitting beam lifetime and calculated beam lifetime.

According to the formulas (3) and (4), the Touschek lifetime and beam-gas scattering lifetime are calculated using the constants c and b. According to the formula (2), the beam lifetime is calculated using Touschek lifetime and beam-gas scattering lifetime, See Fig. 6. It can be seen from Fig. 7 that the calculated beam lifetime and the fitting beam lifetime are almost identical, which verifies the reliability and convenience of the combined analysis method.

SUMMARY

We give an approximate formula for measuring Touschek lifetime and beam-gas scattering lifetime by deriving the formula. Using this method to analyze the beam lifetime of the HLS-II storage ring, it is easy to get the Touschek lifetime and the vacuum life during the operation.

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