MEASUREMENT OF TOUSCHEK LIFETIME IN PLS STORAGE RING*

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Abstract

The Touschek lifetime is determined by the energy acceptance of a storage ring, which is limited longitudinally by the RF system or transversely by nonlinear properties of the lattice or by the vacuum chamber aperture. By measuring the Touschek lifetime by the RF-limited energy acceptance and comparing with the theoretical value, we try to find the contribution from two factors. The Touschek lifetime by the energy acceptance of the transverse motion is also described in this paper.

1 TOUSCHEK LIFETIME

The lifetime is a very important issue at high current operation of 3-rd generation light source in respect of stable and uninterrupted experiment for beam line users. The Touschek lifetime is one of the most significant factors because it gives the minimum value in lifetime and depends on the key machine parameters such as RF voltage and radiation loss.

The lifetime can be expressed as

$$\frac{1}{\tau_{1/2}} = \frac{1}{\tau_g} + \frac{1}{\tau_B} + \frac{1}{\tau_T}, \qquad (1)$$

where τ_g is the gas scattering lifetime, τ_B the Bremsstrahlung lifetime and τ_T the Touschek lifetime. We focus on the Touschek lifetime because the gas scattering lifetime does not depend on the RF acceptance and the Bremsstrahlung lifetime weakly depends on.

The Touschek lifetime can be expressed as [1]

$$\tau_T = \frac{\delta p_x (\Delta p_{rf})^2 V_B}{\sqrt{\pi} r_e^2 c N_b} \frac{1}{C(\varepsilon)} = \frac{\gamma^3 \sqrt{\varepsilon_x / \beta_x} (\Delta E_{rf} / E)^2 V_B}{\sqrt{\pi} r_e^2 c N_b} \frac{1}{C(\varepsilon)}, \qquad (2)$$

where $\delta p_x = p_z \sigma_{x'} = \gamma \sqrt{\varepsilon_x / \beta_x}$ is the horizontal momentum spread of electron beam in the unit of $m_0 c$, Δp_{rf} the RF bucket height in the unit of $m_0 c$, r_e the classical electron radius (=2.8179x10^{-15} m), c the speed of light, N_b the number of electrons per bunch and V_B the bunch volume (= $(4\pi)^{3/2} \sigma_x \sigma_y \sigma_z$), where σ_x, σ_y are the horizontal and vertical rms beam size, and σ_l the bunch length. $C(\varepsilon)$ is the Touschek effect function.

Eq. (2) is the Touschek lifetime considering the RF-limited energy acceptance only. The energy acceptance $(\Delta E_{max} / E)$ of a storage ring is limited longitudinally by the RF system $(\Delta E_{max} / E)_{rf}$ or transversely by nonlinear properties of the lattice or by the vacuum chamber aperture in dispersive ring sections $(\Delta E_{max} / E)_{\perp}$ [2]. For a practical storage ring the energy acceptance of the transverse motion $(\Delta E_{max} / E)_{\perp}$ is usually limited to a few percent and strongly depends on chromaticity. However, the larger is the linear chromaticity, the smaller is the momentum aperture. The Touschek lifetime by the energy acceptance of the transverse motion $(\Delta E_{max} / E)_{\perp}$ is shortly discussed.

Figure 1 shows the one-day trends of beam current and lifetime at 2.5 GeV on May 17 and May 28, 2001. The orbit correction was performed on May 25, 2001, and then the lifetime increased by about 10 hours from the lifetime before correction; almost 40% increase. The lifetime is about 40 hours at the beam current of 100mA.

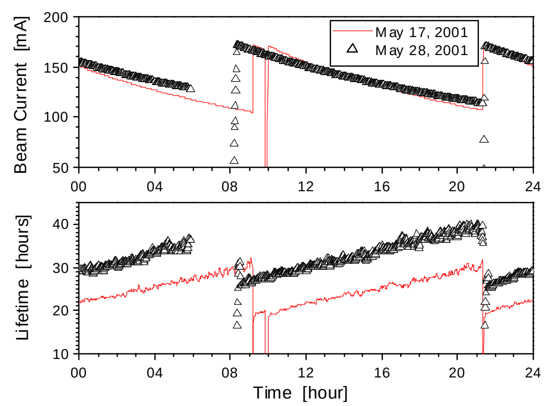

Figure 1: The one-day trends of beam current and lifetime on May 17 and May 28, 2001.

Figure 2 shows the calculated gas scattering lifetime, includes the Bremsstrahlung lifetime hereinafter, and lifetime as a function of half-height of vertical aperture. The Bremsstrahlung lifetime is about 387.5 hours with 1.5% RF acceptance at 2.5GeV. The gas scattering lifetime is 155 nTorr·hours with the minimum gap of 10 mm. The gas compositions are assumed to be 90% H_2, 2% CH_4, 1% H_2O, 6% CO, and 1% CO_2. And the Touschek lifetime lifetime is assumed to be 50 hours at 100 mA and 2.5 GeV. The increase of lifetime after the orbit correction is not solely explained with the increase of gas scattering lifetime due to the increase of minimum vertical aperture. Considering only the contribution of gas

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scattering, the half-height of minimum vertical aperture must be around 2.5 mm before correction as shown in Fig. 2, which is an unrealistic guess. The Touschek lifetime by the energy acceptance of the transverse motion $(\Delta E_{\max} / E)_{\perp}$ contributes to increase the lifetime much more than the gas scattering lifetime.

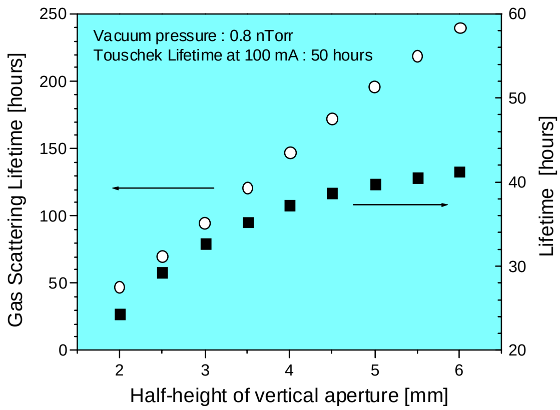

Figure 2: The calculated gas scattering lifetime and lifetime as a function of half-height of vertical aperture.

2 MEASUREMENT OF TOUSCHEK LIFETIME

Figure 3 shows the measured and calculated Touschek lifetime as a function of RF voltage. The beam current is 8 mA and 8 bunches are filled, which simulates a 1 mA single bunch. We use 8 bunches in order to minimize the error in very small beam current measurement by DCCT. The Touschek lifetimes at different x-y coupling are calculated using the beam parameters listed in Table 1. The measured data look close to the case of coupling 0.5%. But this does not represent the real situation.

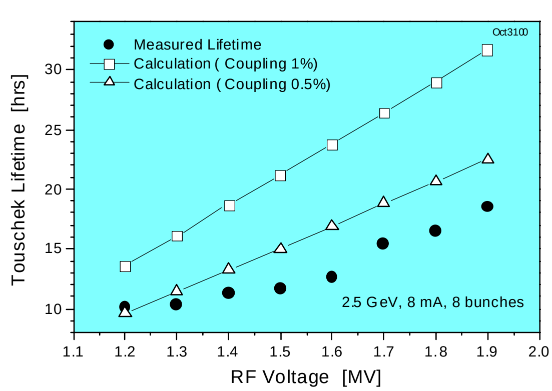

Figure 3: The measured and calculated Touschek lifetime as a function of RF voltage.

Table 1. The beam parameters at 2 GeV and 2.5 GeV. [3]

Beam Parameters	2.0 GeV	2.5 GeV
$\bar{\beta}_x$ [m]	6.52	
$\bar{\beta}_y$ [m]	8.52	
ε_n [nm-rad]	12.1	18.9
x-y coupling [%]	1	1
ε_x [nm-rad]	12.0 (11.7*)	18.7
ε_y [nm-rad]	0.12 (0.59*)	0.187
$\bar{\sigma}_x$ [μm]	294.1	367.7
$\bar{\sigma}_y$ [μm]	30.5	38.1
σ_E	6.8x10^{-4}	8.5x10^{-4}
σ_l** [mm]	5.0	8.05

* The measured data.
** The RF voltage is assumed to be 1.6 MV.

The Touschek lifetime depends on the volume of beam bunch, that is, horizontal and vertical beam size and bunch length. The vertical beam size depends on the x-y coupling. The horizontal and vertical emittances are related to the natural emittance ε_n by

$$\varepsilon_x = \frac{1}{1+\kappa}\varepsilon_n, \qquad \varepsilon_y = \frac{\kappa}{1+\kappa}\varepsilon_n, \tag{3}$$

where the coupling constant κ comes from skew quadrupole components. But the real vertical beam size is much bigger than the calculated value with the x-y coupling. It results from the vertical beam blow-up due to the contribution of nonlinear magnetic field and vertical dispersion.

Figure 4 shows the result of closest tune approach coupling measurement. The measured closest tune frequency is about 10 kHz. The calculated ratio of vertical to horizontal emittance is about 0.009, very small coupling less than 1%. However, the vertical emittance calculated by the beam size measurement which uses the x-ray diagnostic beam line is 3.58 nm, very large value compared with the value in Table 1. It is expected to be due largely to residual vertical dispersion. The coupling contribution, as one sees from the calculation, is small. The difficulty in the measurement of vertical beam size makes the calculation of Touschek lifetime unrealistic so that the calculated vertical beam size using x-y coupling is reasonable to use for the calculation of The Touschek lifetime.

Figure 5 shows the measured Touschek lifetime at 2 GeV and 2.5 GeV as a function of single bunch current. In the measurement a single bunch was used and the average vacuum pressure was 0.416 nTorr. This graph shows also the calculated lifetime for 2 GeV and 2.5 GeV. In the calculation the coupling is assumed 1%. The measured Touschek lifetime at 2GeV looks very close to the calculation which uses the RF acceptance of 2.18%, that corresponds to RF voltage 1.6MV. On the contrary, there is a big difference between the measurement and calculation at 2.5 GeV. The RF acceptance with 1.6 MV at 2.5 GeV is 1.58%. To make close, we introduce the momentum acceptance instead of RF acceptance which includes the contribution of the energy acceptance of the transverse motion. In case the momentum acceptance is 1.35%, the calculation gets close at the high current, higher than 2.5 mA, among the measurement data. It is not clear why the Touschek lifetime at the low current is much shorter than the calculation.

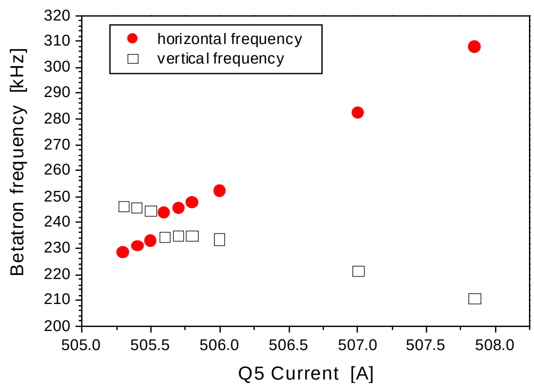

Figure 4: Closest tune approach for coupling measurement. (Sep. 4, 2001)

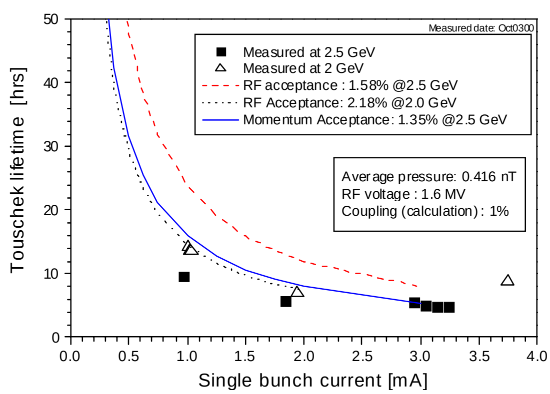

Figure 5: The measured Touschek lifetime as a function of single bunch current (Oct. 04, 2000).

As previously commented, the measured Touschek lifetime at 2GeV is very close to the calculated lifetime, on the contrary a big difference at 2.5GeV as shown in Figure 5. This simply indicates that the calculation using the formula in Eq.(2) is not unrealistic. Using only above results, it is difficult to exactly estimate the contribution of Touschek lifetime by the energy acceptance of the transverse motion. But the momentum acceptance of 1.35% which includes both the RF-limited energy acceptance and the energy acceptance of the transverse motion shows good agreement between the measurement and calculation.

3 CONCLUSION

Even though the vertical beam size for calculation of Touschek lifetime is not measured but calculated with the measured coupling by closest tune approach, the Touschek lifetime is not meaningless, has quite good agreement with the measurement at 2 GeV. The big difference at 2.5 GeV is due largely to the energy acceptance of the transverse motion, not due to the increase of half height of minimum vertical aperture. In order to exactly estimate the contribution of Touschek lifetime by the energy acceptance of the transverse motion, it is required to investigate the frequency map.

4 REFERENCES

[1] H. Bruck: *Accelerateurs Circulaires de Prticules*, Press Universitaires de France, Paris, 1966.
[2] W. Decking and D. Robin, in Proc. Of Nonlinear and Collective Phenomena in Beam Physics 1998 Workshop (Archidosso, 1998), 119.
[3] Pohang Light Source Design Report (Revised Edition), January 1992.