

Beam Lifetime Investigations at SRRC

C.C. Kuo, H.P. Chang, M.H. Wang, W.T. Weng⁺

Synchrotron Radiation Research Center

No 1. R&D Rd VI, Hsinchu Science-Based Industrial Park, Hsinchu, Taiwan, R.O.C.

ABSTRACT

The beam lifetime of the 1.3 GeV storage ring TLS at SRRC was studied. The contributions of the gas scattering lifetime and Touschek scattering lifetime were measured. The effects of the insertion devices, RF energy acceptance, chromaticity setting, transverse emittance coupling strength, bunch length, bunch current, etc., on the beam lifetime were measured. It is observed that this machine is Touschek lifetime dominated provided that the transverse emittance coupling strength is low enough and bunch current is reasonably high. In the multibunch users mode it is required to have a longer lifetime, some possible actions to increase the beam lifetime have been proposed or implemented.

1. INTRODUCTION

Since it was commissioned in April 1993, the 1.3 GeV synchrotron radiation light source, Taiwan Light Source(TLS), of the Synchrotron Radiation Center located in Hsinchu, Taiwan, has been operated for about 3 years.[1-3] The major machine parameters are listed in Table I. After the new chambers were installed during the commissioning periods of the new ring in 1993 and the addition of the insertion devices in 1995 and 1996, the desorpted gases could be reduced to an acceptable amount for a reasonable period of synchrotron radiation cleaning.[4] However, the insertion devices together with associated chambers of smaller aperture strongly affected the beam lifetime. Because the beam lifetime is one of the key performances for the light source users, i.e., most of our users demand an interval of the useful beam time between refills at least no less than 5 hours, thus it is imperative that the improvement of the beam lifetime be investigated.

An attempt to understand the contributions of the loss rate of the stored beam due to the scattering of the electron with residual gases and the scattering between electrons in the same bunch was performed. The measured beam lifetime as a function of bunch current, rf gap voltage, and ring chromaticity in the single bunch mode reveals the dependence of the energy acceptance and dynamic aperture of the ring as well as the dependence of the bunch volume. The reduction of the emittance and the dynamic aperture of the ring in the presence of insertion devices was clearly observed. To increase the lifetime, the emittance coupling was increased by skew quadrupoles.

Table I. TLS Machine Parameters

Circumference	120 m
Nominal Energy	1.3 GeV
Maximum Energy	1.5 GeV
RF frequency	499.654 MHz
Natural beam emittance ϵ_{x0}	$1.92 \cdot 10^{-8}$ m-rad
Natural energy spread	0.066%
Momentum compaction factor	0.00678
Damping time $\tau_x/\tau_z/\tau_s$	10.691/14.397/8.708ms
Betatron tunes ν_x/ν_z	7.18/4.13
Natural chromaticities ξ_x/ξ_z	-15.292/-7.868
Synchrotron tune (RF@800KV)	$.15 \cdot 10^{-2}$
Bunch length (RF@800KV)	0.74 cm
Radiation loss per turn (dipole only)	72.28 keV
Nominal stored current M.B./S.B.	200 mA/5mA
Critical photon energy from bending	1.39 keV
Beam size (σ_x/σ_y , assuming $\epsilon_y/\epsilon_x=1/100$)	
BM1	0.135/0.048 mm
Insertion middle	0.447/0.024 mm

2. SINGLE BUNCH

Single bunch operation has been available since the commissioning of the storage ring started in 1993. The impurity of the side bunches was no more than 1% without using bunch purification system. The study of the single bunch lifetime with such impurity is good enough. We measured the beam lifetime as a function of bunch current up to 30 mA at two different RF voltage settings as shown in Fig. 1. The beam lifetime was inversely proportional to some factor of bunch current above the threshold of microwave instability. The bunch length measured with a streak camera (Hamamatsu C5680) showed that the bunch was lengthened above the threshold of the microwave instability and was approximately in proportion to $I^{1/3}$, which is depicted in Fig. 2. [5]

At low single bunch current, the beam lifetime was measured at different rf gap voltages, different ring chromaticities, and different wiggler pole gaps as given in Fig. 3.

In single bunch operation of low beam current below the threshold of microwave instabilities, the transverse beam size was measured to be a constant value in the case that the emittance coupling was kept constant, i.e., both sextupole strength and beam orbit were not varied. The Touschek lifetime can be expressed as

$$\tau_T \sim (\Delta E / E)^3 \cdot \frac{\sigma_x \sigma_y \sigma_z}{I_b} \quad (1)$$

⁺Permanent address: AGS Department, BNL Upton, NY, USA

Where $\Delta E/E$ is maximum energy deviation acceptance of the electron beam, $8\pi\sigma_x\sigma_y\sigma_l$ is the bunch volume for Gaussian beam in the three-dimensional space, I_b is the bunch current. If the energy acceptance is limited by the rf bucket height, it is in proportion to the square root of the rf gap voltage. At low bunch current, the bunch length is inversely proportional to the square root of the rf gap voltage. The product of Touschek lifetime times bunch current is in proportion to the rf gap voltage. If the energy acceptance is limited by the transverse aperture, the Touschek lifetime is in proportion to the bunch length, i.e., inversely proportional to the square root of the rf gap voltage.

At very low bunch current,

$$\tau_T I \sim V_{rf}, \text{ if } \Delta E/E \text{ limited by the longitudinal plane}$$

$$\sim V_{rf}^{-1/2}, \text{ if } \Delta E/E \text{ limited by the transverse plane} \quad (2)$$

In Fig. 1, at small ring chromaticities ($sd=107A$, $sf=91A$) where $\Delta E/E$ is limited by the longitudinal plane as discussed below and for a constant rf gap voltage, the only variable is bunch length (if the beam instabilities do not occur and the vacuum change is negligible) and the dependence of the lifetime with respect to bunch current includes effects of the bunch lengthening and increase of energy spread. Above the microwave instability threshold ($\sim 4mA$), a curve is fitted with $I^{2/3}$. At very low current, the lifetime is inversely in proportion to bunch current.

In Fig. 3, at low sextupole settings, the lifetime is in proportion to the rf gap voltage as given in Eqn(2). At higher sextupole strength, the vertical emittance increases due to the skew quadrupole term of the closed orbit in the sextupole magnetic field. Therefore, the lifetime is longer at lower rf gap voltage with larger sextupole fields. However, at certain rf gap voltage, the lifetime drops in proportion to the square root of rf gap voltage. Because the beam current was as low as 2 mA, the measured bunch length is inversely proportional to the square root of the rf gap voltage. The maximum energy acceptance is limited by the transverse excursion of the beam orbit at the dispersion region, i.e., the dynamic aperture in the horizontal plan, is the dominant factor of the energy acceptance once the longitudinal energy acceptance is higher than the transverse one. Measurements showed that there was a reduction of dynamic aperture at higher chromaticity. The calculated rf energy acceptance as a function of gap voltage gives 1.6% at 800 KV and 1.2% at 500 KV. At the highest dispersion location $\eta_x=0.67m$ in the achromat, the dynamic aperture thus reduced about 2~3 mm accordingly.

To suppress the vertical beam instabilities without using any transverse feedback system, the chromaticity was increased to more than +3.[6] The lifetime thus was limited by the dynamic aperture. We have developed a

wideband transverse feedback system and with such device the chromaticity could be set near zero ($sd\approx 105A$, $sf\approx 90A$) in the routine operation.[7] At nominal RF gap voltage of 800 kV, the energy acceptance was still limited in the longitudinal plane at zero chromaticity.

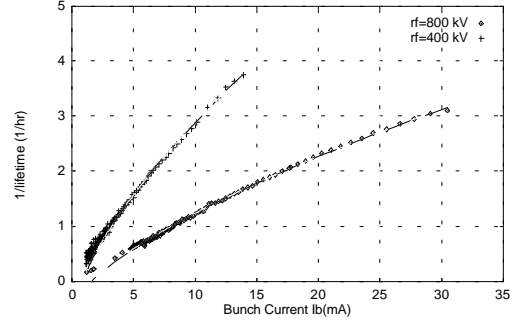


Fig. 1. The dependence of the beam lifetime as a function of bunch current at 400 and 800 KV rf gap voltage with ring chromaticities near zero. The chromaticity was near zero. The dashed lines are fitted with $I^{2/3}$ above 4 mA.

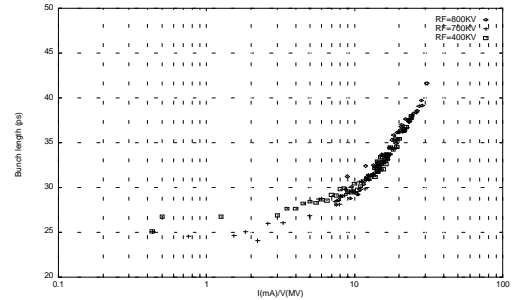


Fig. 2. The dependence of the bunch length as a function of bunch current and rf gap voltage. The microwave instability is clearly seen.

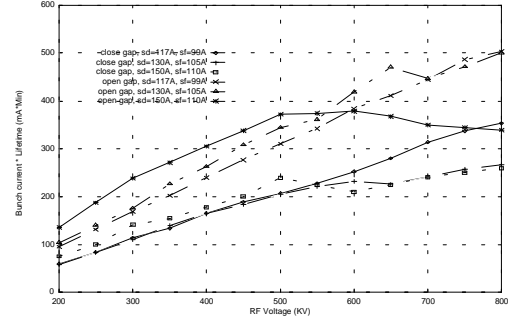


Fig. 3. The dependence of the beam lifetime of single bunch operation at low bunch current below microwave instability as a function of rf gap voltage for different sextupole settings in both cases of wiggler open and close.

In Fig. 3, the lifetime reduced significantly when the wiggler magnetic pole gap was closed. Two reasons have been identified. One is that the wiggler is a damping wiggler and the other is that the dynamic aperture is shrunk once the wiggler is fully closed. These two effects have been experimentally measured and theoretically calculated. The wiggler pole period is 20 cm long and the effective pole number is 25. The peak

field strength is more than 1.8 Tesla at the minimum wiggler gap 22 mm. Introduction of such a wiggler field in the ring lattice caused emittance reduction by 15%. The scraper experiment reveals the reduction of dynamic aperture by 1~2 mm in the long straight.

In comparison with the theoretical calculation results, an emittance coupling of 3% was fitted to the experimental value. This emittance coupling was also in agreement with the beam size measurement result.

3. MULTIBUNCH

In the multibunch operation, the gas scattering lifetime was about 15~25 hours before we installed the long straight chamber of smaller inner aperture for the insertion device U5. The vertical aperture was about 9 mm (full aperture) for U5 and the measured aperture using scrapers was about 6~7 mm. It is not easy to get reliable gas lifetime using the beam blow-up method because of the small vertical aperture. We anticipated that gas lifetime was reduced by a factor of 2~3 due to aperture change from 5.5mm (vertical dynamic aperture) to 3.5 mm (vertical half physical aperture). With the beam loss monitor system, which consisted of 48 PIN diodes, we observed much higher beam loss in this small chamber. The average vacuum pressure was about 1~2 nTorr at 200 mA while the base pressure was about 0.5 nTorr. The lifetime at 200 mA for partial filling with 150 bunches out of 200 rf buckets was about 5.5 and 3 hours for wiggler gap open and close, respectively, before the U5 chamber was installed. It reduced to 3.5 and 2.5 hours in the presence of the U5 chamber. To increase the lifetime, we increased the vertical emittance coupling by skew quadrupole. For example, with the increase of vertical beam size by a factor of about 1.5, the lifetime then increased accordingly. In this operation mode, the users gain a longer lifetime with the sacrifice of photon brightness. However, in the time being, the larger emittance coupling mode is acceptable for most of the users.

Owing to the longitudinal coupled bunch instabilities the bunch was lengthened and the bunch volume increased in both transverse planes. In the multibunch mode operation, the lifetime as a function of the bunch current then increased for higher ring current.

Fig. 4 gives the decay rate as a function of the inverse of the square of the vertical half aperture in the multibunch operation at zero chromaticity with U5 chamber at different beam current, in which the wiggler magnetic pole gap was open, the transverse feedback system was employed, and the vertical emittance coupling was increased by skew quadrupoles.

4. DISCUSSION

The beam lifetime of the TLS is limited by the Touschek lifetime for a reasonable vacuum pressure of 1~2 nTorr. The energy acceptance is determined by the

dynamic aperture or rf bucket height, whichever is smaller. The introduction of the smaller beam chamber for insertion devices of smaller magnetic pole gap resulted in the reduction of the gas lifetime. The wiggler magnet caused a reduction of natural emittance as well as the shrinkage of the dynamic aperture and, as a consequence, the lifetime was reduced significantly. The blow-up of vertical beam size by skew quadrupoles gave an increase of lifetime by a factor of 1.5 or so. A study to increase lifetime by adding the third rf system, which will raise the longitudinal energy acceptance, as well as a harmonic cavity, which will lengthen the bunch length, is going on. Moreover, the improvement of gas lifetime, such as the increase of the physical aperture and clearing up rf heating problem at high bunch current, is also needed. The operation at higher beam energy such as 1.5 GeV will increase the beam lifetime.

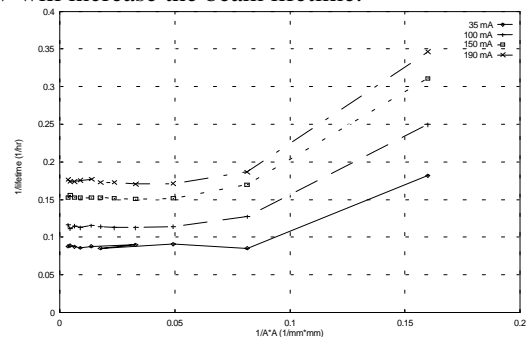


Fig. 4. The decay rate as a function of the inverse of aperture square at different operation energy while wiggler gap was open and transverse feedback was on. The chromaticity was near zero and skew quadrupoles were excited.

5. ACKNOWLEDGMENT

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