LIFETIME STUDIES AT THE ADVANCED LIGHT SOURCE

W. Decking, J. Byrd, C. Kim, D. Robin, LBNL, Berkeley, USA *

Abstract

We show measurements of the lifetime of the ALS while varying conditions such as the transverse and momentum apertures, current density in the bunch, etc. These measurements allow to distinguish between the different lifetime limiting effects (especially Touschek effect and elastic scattering) and give an experimental basis for making future decisions to improve the lifetime.

1 LIFETIME LIMITING PROCESSES

The Advanced Light Source (ALS), operated at the Lawrence Berkeley National Laboratory, is a third generation synchrotron light source optimized for high brightness synchrotron radiation in the VUV and soft x-ray regime. The storage ring is designed as a low emittance storage ring and operates at energies of 1.5 GeV or 1.9 GeV, storing 400 mA in approximately 300 bunches. The nominal horizontal emittance at 1.5 GeV is 3.5 nm rad, with an emittance coupling of $\approx 1\%$ achieved so far. The nominal bunch length is $\sigma_s \approx 5$ mm. Multi-bunch feedback systems control transverse and longitudinal multi-bunch instabilities, thus keeping the beam size small even for high multi-bunch currents.

The lifetime in the ALS is one of the most important operational parameters. Longer lifetimes are favorable out of several reasons: longer time spans to set up and run experiments, less thermal variations of the vacuum chamber and beam line optics components, and more photons for the experimenters.

The lifetime in an electron storage ring is usually determined by the following effects: quantum excitation (τ_q), elastic (τ_{el}) and inelastic scattering (τ_{inel}) on the residual gas atoms, scattering of electrons within the bunch (Touschek-effect) (τ_{tou}), and trapping of charged particles in the beam potential (τ_{ion}). The total lifetime becomes:

$$\frac{1}{\tau_t} = \frac{1}{\tau_q} + \frac{1}{\tau_{el}} + \frac{1}{\tau_{inel}} + \frac{1}{\tau_{tou}} + \frac{1}{\tau_{ion}} \qquad (1)$$

In this paper, we focus on measurements of the Touschek and elastic scattering lifetime and omit the other contributions out of the following reasons: The quantum lifetime is only important for apertures which are smaller than $\approx 6\sigma$. All apertures in the ALS are well above this limit. So far, no malignant ion effects have been observed at the ALS under standard operation conditions. To calculate τ_{inel} the average pressure $\langle P \rangle$ and the momentum aperture ε have to be known. This parameters are obtained from measurements of τ_{el} and τ_{tou}.

The functional dependencies of the Touschek and elastic scattering lifetime on different storage ring parameters are as follows:

• Elastic Scattering [4]:

$$\frac{1}{\tau_{el}} \sim \frac{1}{E^2} \left(< \beta_x P > \frac{\beta_x}{A_x^2} + < \beta_y P > \frac{\beta_y}{A_y^2} \right) \qquad (2)$$

E is the beam energy, and $A_{x,y}$ are the transverse apertures, which are given either by the vacuum chamber size or the borders of stable particle motion (dynamic aperture). $\beta_{x,y}$ are the β-functions, $\langle P \rangle$ is the average nitrogen equivalent gas pressure [1] around the ring and $\langle \beta_{x,y} P \rangle$ the average product of the local pressures and β-functions around the ring. The gas pressure (and distribution) varies with varying total beam current due to desorption effects:

$$\langle P \rangle = \langle P_0 \rangle + \left\langle \frac{dP}{dI_t} \right\rangle I_t \qquad (3)$$

where $\left\langle \frac{dP}{dI} \right\rangle$ is the average gas desorption coefficient and I_t the total beam current.

• Touschek Lifetime:

When electrons scatter within a bunch, they may transfer enough momentum to be outside the momentum aperture of the storage ring. The scattering rate is proportional to the electron intensity within a bunch. With a flat beam [2] the Touschek lifetime becomes [1]:

$$\frac{1}{\tau_{tou}} \sim \frac{1}{E^3} \frac{I_b}{V_b \sigma'_x} \frac{1}{\varepsilon^2} f(\varepsilon, \sigma'_x, E) \qquad (4)$$

I_b is the bunch current, V_b the bunch volume, and σ'_x the horizontal velocity spread. ε is the momentum aperture of the storage ring and can be determined by either the size of the rf bucket, the transverse aperture, or a combination of both. The bunch volume as well as the momentum aperture vary around the ring, thus the Touschek lifetime has to be averaged around the ring.

Typical behavior of the lifetime of the ALS over several user runs is shown in figure 1 for the two standard operating conditions, i.e. storage ring energy of 1.5 GeV or 1.9 GeV. The inverse lifetime is plotted versus the total current in the machine, which is approximately equally distributed into 288 bunches. Each line in the plot represents a user run of approximately 4 hours, in which the current drops from 400 mA to about 150 mA. The inverse lifetime

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[1] The main contributions to the residual gas in the storage ring vacuum are measured to be 25 % C0, 25 % CO_2, and 50 % H_2.

[2] This assumes the main contribution of the velocity spread coming only from horizontal motion. Recent work at the ALS extended this one-dimensional theory to the general three-dimensional case, taking into account the velocity spread in all three dimensions [3]. For standard ALS operating conditions, the new theory agrees with the classical one within 10%.

is expected to be proportional to the current, which can be seen by combining equations 2, 3, and 4. For high currents the lifetime behavior differs slightly from this expectations. In addition, for the 1.5 GeV conditions the lifetime varies strongly from run to run and also during a run. At 1.9 GeV the lifetime behavior is very reproducible.

Several measurements were done to get a better understanding of the effects which determine the lifetime in the ALS. The results of these measurements allow to differentiate between the various effects and point towards possible solutions to improve the lifetime.

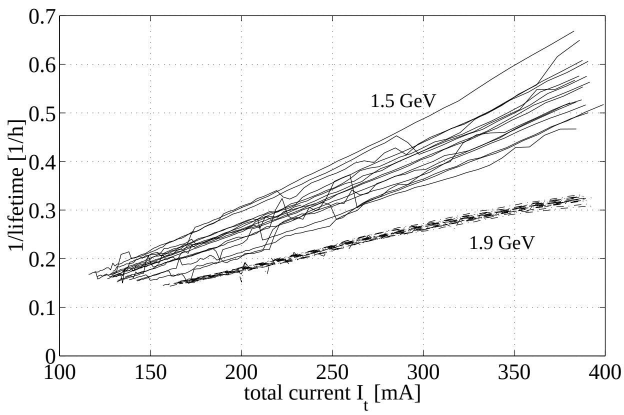

Figure 1: Inverse beam lifetime as a function of the total current for standard user operations. Each line represents a 4 hour user run. The upper curves show the lifetime for 1.5 GeV, while the lower curves are for 1.9 GeV operation.

2 ELASTIC SCATTERING LIFETIME

The elastic scattering lifetime depends on the available transverse aperture. The transverse aperture can be varied with beam scrapers. The dependency of the lifetime on the scraper positions can reveal information about the gas pressure at the beam position, the transverse beam sizes, and the limiting transverse aperture.

The Touschek lifetime depends indirectly on the scraper position. Inserting a scraper reduces the momentum aperture of the storage ring. The scraper measurements were thus done at a low bunch current to minimize the contributions from the Touschek effect.

Results of several measurements with horizontal and vertical scrapers are shown in figure 2. These measurements were done at 1.5 GeV with 5 mA stored in 288 bunches. Equation 2 is fitted to the data by varying the average pressure $\langle P\rangle$ and adding a constant term which accounts for all scraper independent lifetime contributions. As an additional fit parameter the limiting transversal aperture $A_{x,y}$ in the direction that is not varied by the scraper is put into equation 2. From these measurements, the average pressure around the ring is $\langle P\rangle \approx 5\cdot 10^{-10}$ mbar for the horizontal scraper and $\langle P\rangle \approx 2\cdot 10^{-10}$ mbar for the vertical scraper. This discrepancy could be a result of the gas

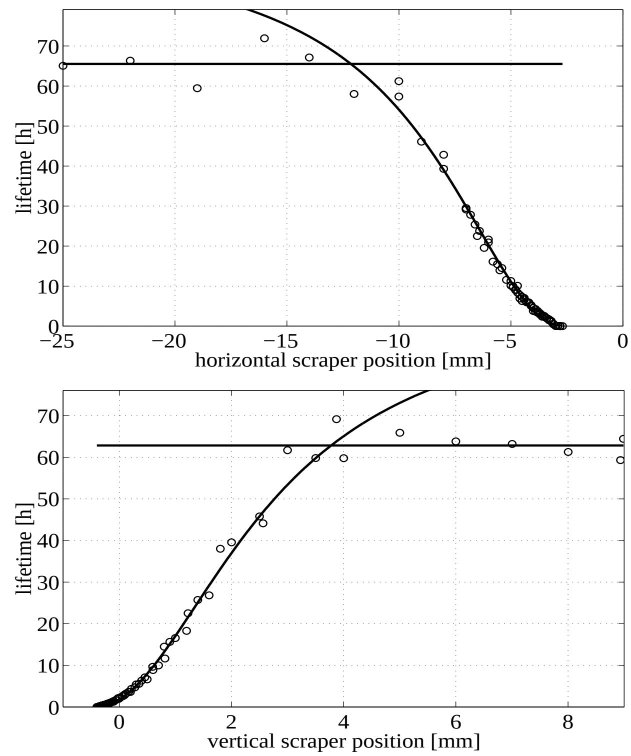

Figure 2: Lifetime as a function of the horizontal (upper) and vertical (lower) scraper position. The storage ring parameters were 5 mA in 288 bunches, beam energy 1.5 GeV.

not being evenly distributed around the ring but concentrated in areas where the ratio of the horizontal to the vertical β-functions is 5/2, as for example in the straight sections. Assuming these β-functions, the average pressure is $\langle P\rangle \approx 3\cdot 10^{-10}$ mbar.

We define the transverse aperture $A_{x,y}$ as the point where the lifetime stays constant with changing scraper positions. The horizontal aperture becomes $A_x \approx 10-12$ mm, which is much smaller than what we expect from tracking calculations. The vertical aperture is $A_y \approx 3.5-4$ mm, which is in agreement with the physical aperture of the narrow gap chambers.

Repeating these measurements at high currents is difficult. Variation of the lifetime with current can not be neglected anymore. In addition the beam becomes unstable, thus varying the beam size. We therefore rely on gas pressure measurements to obtain the relative increase of the gas pressure with higher currents. We also measured the lifetime at high current with fully coupled beam, thus suppressing the contribution of τ_{tou} as much as possible. The gas pressures obtained from these measurements agree with a desorption coefficient of: $\frac{dP}{dI} \approx 1.75\cdot 10^{-12}\frac{\mathrm{mbar}}{\mathrm{mA}}$.

3 TOUSCHEK LIFETIME

A measurement of the lifetime at the same total current but with varying bunch currents (i.e. number of bunches) is shown in figure 3. As the total current (and thus the gas

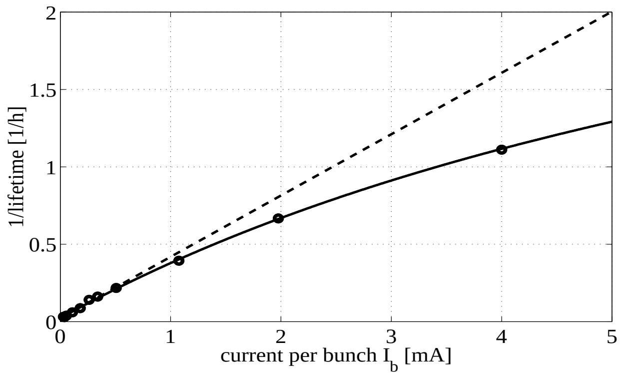

Figure 3: Inverse lifetime versus bunch current at 1.5 GeV. The total current was kept constant at 8 mA.

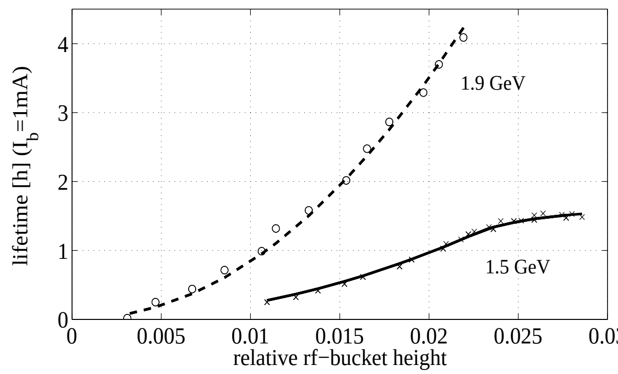

Figure 4: Lifetime versus rf-bucket height for 1.9 GeV (dashed line) and 1.5 GeV (solid line). 8 mA in 8 bunches were stored.

pressure) does not change in this experiment, the slope of the linear (dashed) line gives the change of the Touschek lifetime with bunch current at 1.5 GeV for small total bunch currents:

$$\frac{1}{\tau_{tou}} = 0.4 \left[\frac{1}{\mathrm{h} \cdot \mathrm{mA}}\right] I_b \tag{5}$$

For higher bunch currents, several effects change the volume of the bunch: intrabeam scattering, resistive wall and microwave instabilities. The following simplified model is used to fit the data for higher bunch currents:

$$V_b = V_{b,0}(1 + \frac{dV_b/V_{b,0}}{dI_b} I_b) \tag{6}$$

In this case the bunch volume increases by roughly $0.1\frac{1}{\mathrm{mA}}$.

An important parameter for τ_{tou} is the momentum aperture ε, which can be varied by changing the amplitude of the accelerating rf. Figure 4 shows the lifetime as a function of the rf voltage (given here in units of the relative rf-bucket height) for 1.5 GeV and 1.9 GeV. Equation 4 was fitted to the data points. For the 1.9 GeV case we are clearly limited by the available rf voltage, while at 1.5 GeV the lifetime starts to saturate, thus indicating that the transverse aperture limit is reached. We refer to another paper at this conference, which discusses the details of the momentum aperture [2].

4 SUMMARY

The following table summarizes the different contributions to the total beam lifetime as measured for 1.5 GeV and 288 bunches and a total current of 5 mA and 400 mA. At this standard operating conditions the Touschek lifetime dominates the total beam lifetime. But even with a fully coupled beam, measurements showed that the lifetime does not exceed 14 hours.

As the Touschek lifetime is the limiting effect for ALS operations, several options are available to increase it. The most obvious is to increase the bunch volume. This is done at 1.5 GeV operation by increasing the vertical beam size with the help of skew quadrupoles. The strong coupling accounts for the lifetime variations shown in figure 1. Any slight change of the working point (for example due to the change of an insertion device gap) changes the vertical beam size and thus the lifetime. Large transverse coupling leads to a reduction in the brightness. A better way to increase the beam volume is to elongate the beam with the help of a 3rd harmonic cavity. Such a system, comprising five 1.5 GHz copper cavities is scheduled to be installed in 1999.

Table 1: Contributions of the different lifetime effects to the total lifetime at 5 mA and 400 mA and 1.5 GeV.

		5mA	400 mA
elastic scattering lifetime	[h]	85	≈ 18
inelastic scattering lifetime	[h]	265	≈ 60
Touschek lifetime	[h]	≈ 150	1.8
total lifetime	[h]	≈ 45	≈ 1.6

The other possibility is to increase the momentum aperture ε. At a beam energy of 1.5 GeV the measured momentum aperture is smaller than we expect. The reason for this is currently under investigation. However, at a beam energy of 1.9 GeV the momentum aperture is limited by the available rf voltage. Plans are underway to increase the rf voltage.

5 REFERENCES

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