LIFETIME STUDIES IN THE LNLS ELECTRON STORAGE RING

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Abstract

In this paper, we present a set of measurements performed at the 1.37 GeV electron storage ring of the Brazilian Synchrotron Light Source. We measured the beam lifetime as a function of current per bunch, gap voltage and the position of vertical scrapers. Those measurements helped us to determine the contribution of various particle loss mechanisms (Touschek, elastic and inelastic scattering) to the lifetime of the beam. Comparison with theory is also presented as well as an interpretation of each effect.

INTRODUCTION

The Brazilian Synchrotron Light Source (LNLS) is based on a 1.37 GeV electron storage ring with a 120 MeV injector Linac and a 500 MeV Booster Synchrotron. The nominal horizontal emittance at high energy is 98 nm.rad with a betatron coupling coefficient that can be varied from 0.3% up to 3%. The ring operates with a current of 250 mA in 148 bunches and the typical lifetime during users shifts is approximately 10 hours at maximum current.

A longer lifetime is desired since it would allow higher integrated photon flux to be delivered for user's shifts and a reduction in thermal transients of machine components such as vacuum chamber and magnets as well as optical components in the beam lines.

Measurements of the beam lifetime as a function of some machine parameters such as stored current, gap voltage and scraper position were performed and in each set an effect responsible for particle losses was evidenced. Using those data we were able to determine which are the main scattering process that limit the lifetime of the LNLS storage ring.

THEORY

Particles travelling in a circular accelerator can be lost due to a variety of causes. The effects that are related to these losses determine the beam lifetime, which is an important parameter for storage rings. The lifetime for an electron storage ring is usually determined by the following effects: beam gas interactions which include elastic (τ_{ela}) and inelastic (τ_{ine}) scattering on nuclei of residual gas atoms, electron-electron scattering within the bunch (Touschek effect) (τ_{tou}) and quantum excitation (τ_q). The expression for the total lifetime becomes:

$$\frac{1}{\tau} = \frac{1}{\tau_{ela}} + \frac{1}{\tau_{ine}} + \frac{1}{\tau_{tou}} + \frac{1}{\tau_q} \qquad (1)$$

This paper is focused on the study of the contribution of the Touschek , elastic and inelastic scattering lifetime and disregards the quantum lifetime since it is only relevant for apertures smaller then $\approx 6\sigma$ and all apertures in the LNLS machine are well above this limit.

The expression for the contribution of these effects can be written as follows [1]:

$$\frac{1}{\tau} = \frac{1}{\tau_0} + \frac{1}{\tau_1} \qquad (2)$$

in which

$$\frac{1}{\tau_0} = \frac{b_I}{(x-x_0)^2} \qquad (3)$$

$$\frac{1}{\tau_1} = -a_I\left(\ln(\varepsilon_{RF}) + \frac{5}{8}\right) - c_I\frac{\ln(\varepsilon_{RF}^2) + 4.4}{\varepsilon_{RF}^2} \qquad (4)$$

where $a_I = a(P_0{+}P_1 I)$, $b_I = b(P_0{+}P_1 I)$ and $c_I = cI$. In equations (3) and (4) a, b and c are the inelastic, elastic and Touschek terms respectively, P_0 is the base pressure and $P_1 = \frac{dP}{dI}$ the gas desorption coefficient, x is the vacuum chamber limiting half-aperture, x_0 is the offset of the beam centroid with respect to the scraper central position, I is the stored current and ε_{RF} is the RF momentum acceptance.

MEASUREMENTS AND RESULTS

We measured the lifetime as a function of vertical scrapers position, gap voltage and current. Using equations (3) and (4) we managed to isolate each contribution to the beam lifetime and determine the coefficients a, b and c.

Lifetime in Users Shifts

The typical behavior of the lifetime in the LNLS storage ring over several runs is shown in Figure 1 for multi-bunch and single bunch modes, both at standard operation conditions (1.37 GeV). The inverse lifetime is plotted as a function of the total stored current. All lines correspond to users shifts of about 8 hours in which the current drops from 250 mA to approximately 100 mA. The inverse lifetime is expected to vary linearly with the current as described by the coefficients a_I, b_I and c_I. Note that from the end of 2003 to the beginning of this year (2004) the behavior of the lifetime changed dramatically and now it is longer but much less reproducible. We believe that this effect is due to the insertion of a new RF cavity at the end of 2003 which brought longitudinal oscillations related with HOMs in the new cavity and possible longitudinal bunch dilution that would enlarge the Touschek lifetime.

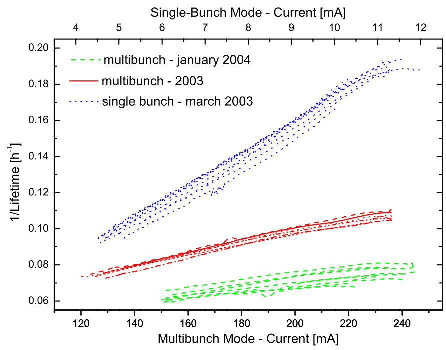

Figure 1: Inverse of beam lifetime for standard users shifts. Each line represents a user shift of approximately 8 hours in two different modes: single bunch and multi-bunch.

Lifetime versus Scraper Position

The LNLS storage ring is equipped with a set of vertical an horizontal scrapers at a non dispersive straight section of the ring, those scrapers were used to measure the contribution of coulomb scattering on the nuclei of the residual gas atoms to the lifetime. The present measurement was done at 1.37 GeV for beam currents in a range of 10 to 50 mA.

Before determining the b_I coefficient we fitted equation (3) to the data considering that, during the experiment with the blades, τ_1 was constant. The results gave us the value of x_0 and τ_1, so we could remove both offsets (in position and lifetime) from the data obtained and fit a straight line to find the b_I dependence with the stored current shown in Figure 2.

From the slope of the fit we obtain the value of $bP_1 = 0.053 \pm 0.006$ mm^2 mA^{-1} h^{-1}. The b coefficient depends upon the particles energy, the value of the betatron function at the scraper position and its mean value around the ring. For the LNLS storage ring $b = 3.8$ mm^2 h^{-1} nTorr^{-1} and this gives $P_1 = (1.4 \pm 0.2) \times 10^{-11}$ Torr mA^{-1}. A comparison with data from an ion gauge inside a dipole vacuum chamber, which measures a dynamic pressure of 1×10^{-11} Torr mA^{-1}, shows a good agreement with the estimated value for P_1.

Lifetime versus current per bunch

A measurement of the lifetime in single bunch mode for several values of stored currents were performed and the results are shown on Figure 3. As described by equation (4) the inverse lifetime varies linearly with the bunch current.

From the linear fit of the data it was possible to determine the Touschek coefficient $c = (2.78 \pm 0.01) \times 10^{-7}$ h^{-1} mA^{-1}. The theoretical value for this coefficient varies from 3.5 to 1.2 $\times 10^{-7}$ h^{-1} mA^{-1} with a coupling coefficient of 0.3% to 3% [2] and a total gap voltage of 320 kV.

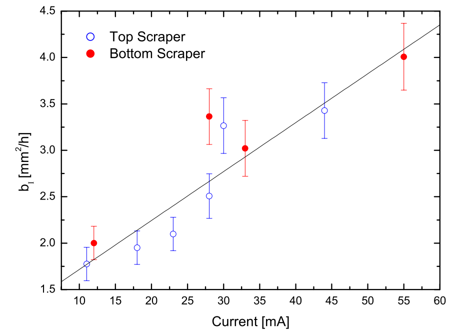

Figure 2: Variation of elastic scattering term b_I with current.

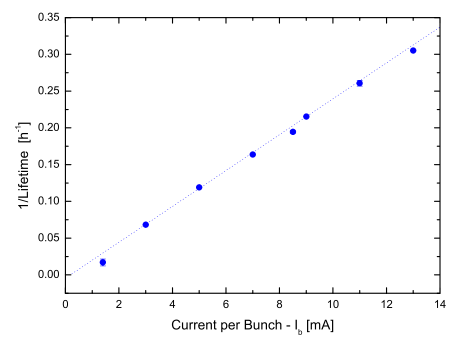

Figure 3: Variation of the inverse of the lifetime as a function of the bunch current. All data refers to a total accelerating voltage of 320 kV.

Lifetime versus RF Momentum Acceptance

A measurement of the beam lifetime as a function of the acceleration voltage was performed and equation (4) was fitted to the data as shown in Figure 4.

The values for the coefficients obtained from the fit are displayed in Figure 5a. The dependence of a_I with current comes from the dynamic pressure, that increases with the stored current, whereas the dependence of c_I with current comes from Touschek lifetime dependence with bunch density.

Table 1: Comparison of the measured a and c coefficients with its theoretical values (assuming a 0.5% coupling).

Coefficient	Measurement	Theory
a [x 10^{-3}h^{-1} nTorr^{-1}]	4 ± 1	4.8
c [x 10^{-7}h^{-1} mA^{-1}]	2.3 ± 0.4	2.7

A comparison of the measured values and the theoretical ones is in Table 1 were we have used the result obtained for P_1 in the previous section to calculate a.

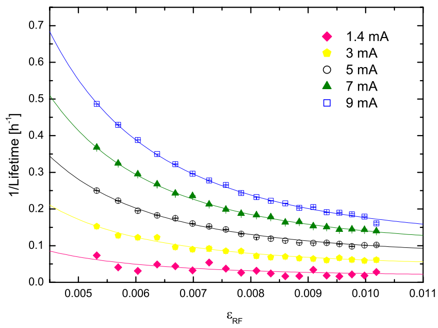

Figure 4: Inverse lifetime as a function of the RF momentum acceptance. The measurements were performed in single bunch mode with currents of : 1.4, 3, 5, 7 and 9 mA. The solid lines correspond to fitted data in each case.

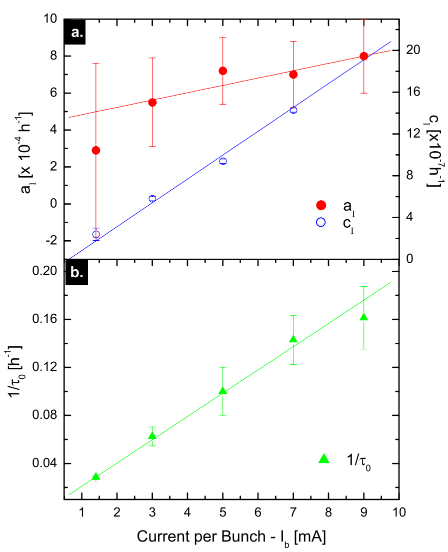

Figure 5: Results from the fit of equation (4): **a.** Dependence of the inelastic (a) and Touschek (c) coefficients on the current per bunch and **b.** $1/\tau_0$ coefficient as a function of the current per bunch. The solid lines correspond to a linear fit to the data.

SUMMARY

The following table summarizes the contribution of various effects to beam lifetime, as measured, and a comparison with theoretical predictions. The measured values for the lifetime were obtained from equation (2) using coefficients a, b and c measured.

At standard operating conditions Touschek scattering represents the limiting factor to achieving a higher beam lifetime at the LNLS ring. There are several ways to increase it: using a 3^{rd} harmonic cavity, increasing the vertical beam size or the momentum aperture. The first is a rather expensive solution and the second leads to a reduction of brightness. Increasing the momentum aperture, by means of the RF voltage, does not give a definite solution as we reach a saturation at the voltage around 500 kV with sets a limit to the overall lifetime of approximately 20 hours.

Another possibility is trying to elongate the beam using RF phase or voltage modulation. Exploratory experiments were done showing that an increase can be gained using this technique (Figure 6) and further study about this subject is in progress at the moment.

Table 2: Lifetime for standard operating conditions with 250 mA at 1.37 GeV, accelerating voltage of 350 kV and 0.5 % coupling.

Lifetime	Measured [h]	Theory [h]
Elastic	62	58
Inelastic	59	50
Touschek	27	30
Total	14	14

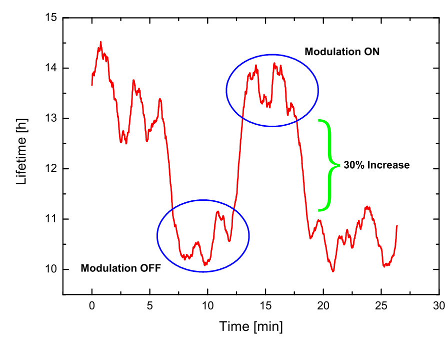

Figure 6: Lifetime variation due to phase modulation at approximately twice the synchrotron frequency (32.8 kHz), amplitude of 4^o and total gap voltage of 320 kV.

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