STUDIES OF BEAM LIFETIME AT ANKA

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Abstract

Beam lifetime studies have been performed at the 2.5 GeV electron storage ring ANKA. Measurements under different condition allow to differentiate between Touschek, elastic and inelastic beam lifetimes. The measurements are compared with theoretical predictions.

INTRODUCTION

ANKA is a Synchrotron Radiation facility with a nominal energy of 2.5 GeV, a horizontal emittance of 90 nmrad and currents up to 200 mA. The desired user mode is one injection per day. Thus long lifetimes are important. Presently typical lifetimes are larger than 30 h for a current of 100 mA.

The beam lifetime is determined by scattering of the electrons at the nucleus and the shell of the atoms of the residual gas (gas lifetime) and the scattering of electrons within a bunch (Touschek lifetime). For low RF voltages also the quantum lifetime becomes important.

THEORETICAL FORMULAE

The lifetime of the electrons in an storage ring is determined by the inelastic (i) and the elastic scattering (e) at the nuclei (N) and at the electrons (e) of the residual gas, and the Touschek scattering (τ_T). The expressions for the different contributions are given by [1]:

$$\frac{1}{\tau_{total}} = \frac{1}{\tau_e^N} + \frac{1}{\tau_i^N} + \frac{1}{\tau_e^e} + \frac{1}{\tau_i^e} + \frac{1}{\tau_T} \quad [1]$$

$$\frac{1}{\tau_e^N} = \frac{2\pi\, r_e^2}{\gamma^2} Z^2\, c\, n_G\, n \frac{\langle\beta\rangle \beta_a}{a^2} \quad [2]$$

$$\frac{1}{\tau_i^N} = \frac{4 r_e^2 Z^2}{137} c\, n_G\, n\, \frac{4}{3} \left(\ln\frac{183}{Z^{1/3}}\right)\left(\ln\frac{1}{\Delta p/p} - \frac{5}{8}\right) \quad [3]$$

$$\frac{1}{\tau_e^e} = \frac{2\pi r_e^2 Z}{\gamma} c\, n_G\, n\, \frac{1}{\Delta p/p} \quad [4]$$

$$\frac{1}{\tau_i^e} = \frac{4 r_e^2 Z}{137} c\, n_G\, n\, \frac{4}{3}\left(\ln\frac{2.5\gamma}{\Delta p/p} - 1.4\right)\left(\ln\frac{1}{\Delta p/p} - \frac{5}{8}\right) \quad [5]$$

$$\frac{1}{\tau_T} = \frac{r_e^2 c n_e D(\varsigma)}{8\pi\, \gamma^2 (\sigma_x \sigma_y \sigma_z)\,(\Delta p/p)^3} \quad [6]$$

with, $D \sim \sqrt{\varsigma}\left(-\ln(1.78\,\zeta - 1.5)\right)$ and $\varsigma = \left(\frac{\Delta p/p\ \beta_x}{\gamma\ \sigma_x}\right)^2$ [7]

The symbols used in the above formulae and their typical values are given in Table 1.

Table 1: Symbols used in this text and their typical values

γ	Lorentz factor	4892 for 2.5 GeV
r_e	Classical electron radius	$2.8\ 10^{-15}$ m
c	Velocity of light	$3\ 10^{8}$ m/s
Z	atomic number of residual gas	7
n_G	Residual gas density	$2.47\ 10^{20}$ for 1 Pa
n	Residual gas (CO), atoms per molecule	2
n_e	electrons per bunch	$5\ 10^{9}$
$\Delta p/p$	Energy acceptance	0.01
a_s	Vertical half aperture	8 mm
βs	Beta function at aperture	9.5 m
σ_x	Rms horizontal beam size, avg	0.67 mm
σ_y	Rms vertical beam size, avg	0.12 mm
σ_z	Rms bunch length	12 mm

For the residual gas a Z=7 is assumed, which is in accordance with a real gas composition made of H_2 (not contributing, due to the low Z) and CO as measured with a mass spectrometer in the storage ring.

The contribution from the elastic scattering with the electrons of the residual gas is negligible and will not be considered any further.

MEASUREMENTS AND RESULTS

Lifetime versus current

Both the gas lifetime and Touschek lifetime depend on the current. The Synchrotron Radiation induces gas desorption which is proportional to the current and the Touschek lifetime depends linearly on the bunch current. Fig. 1 shows this dependence as a function of total current for 1.7 and for 2.7 % betatron coupling between the horizontal and the vertical plane.

ANKA is run most of the time with a 2.7 % coupling in order to increase the lifetime.

The measurements were performed with a total RF voltage of 1360 kV. The beam current was distributed in 25 bunches. Extrapolating the measurements to zero current, where the Touschek contribution should be negligible, the data indicates a limit to the lifetime of 42 h due to gas lifetime. This lifetime is now shorter than before the vacuum chamber was contaminated with Kr [2].

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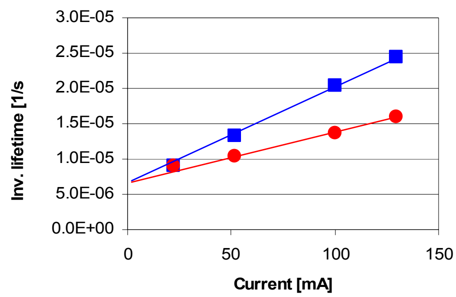

Figure 1: Inverse lifetime as a function of current for 1.7 % (square) and 2.7 % (circles) coupling.

Longitudinal quantum lifetime

If the RF Voltage is reduced to a level below 1000 kV the quantum lifetime becomes dominant. This is shown in Fig.2.

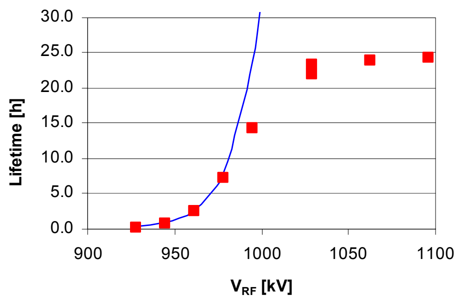

Figure 2: Lifetime as a function of the RF Voltage, squares correspond to measured data, line is the calculated quantum lifetime at low voltage points

The drop of the lifetime is very sharp and depends on the exact energy, RF voltage and momentum compaction factor. Since the exact energy and momentum compaction factor were determined using resonant depolarisation [3], a calibration factor for the RF voltage could be determined to be 0.93.

Elastic gas scattering lifetime

Measurements of lifetime as a function of the position of a vertical scraper can be used to determine the elastic component of the gas lifetime. At ANKA a scraper is positioned at the end of a long straight section. It has two blades, which can be operated from top and bottom independently. The present measurements were done at 2.5 GeV for beam currents of 50 and 90 mA. The measurements when moving the top blade for a current of 50 mA are shown in Figure 3.

It turned out that the bottom blade could be moved further in than the top one for the same effect on the beam. This is due to an offset of the center of the scraper compared to the center of the electron beam.

Equation 2 for the Coulomb scatering can be written as:

$$\frac{1}{\tau_e^N} = C\frac{1}{a^2} \qquad [8]$$

where C is a constant that depends on residual gas pressure, beam energy and betatron functions.

The measured data have been fitted to equation 8 assuming an additional scraper independent contribution from Bremstrahlung and Touschek scattering.

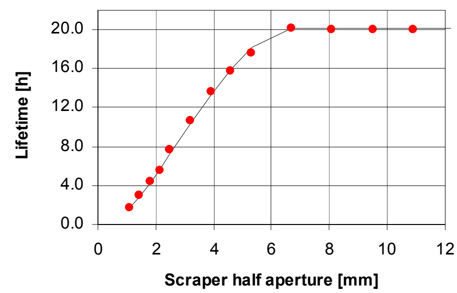

Figure 3: Lifetime as a function of the scraper position

The fit gave the following values for the measurements with 50 mA,

$$\tau_e^N\,[h] = 1.5\,a^2 \qquad \textit{for } a \le 6\ mm$$

$$\tau_{others} = 32\ h$$

The 6 mm limit is smaller than the half aperture of 8 mm in the wiggler vacuum chamber, which is assumed to be the limiting aperture. In addition, the fit gave a +/-0.6 mm offset for the top and the bottom blade respectively. Theoretical predictions indicate a pressure of $1.4\text{x}10^{-9}$ mbar (CO) to obtain the factor 1.5. The average pressure measured at the gauges was $1.2\text{x}10^{-9}$ mbar (for 90% H_2 +10 % CO).

Measurements were also performed at injection, i.e. 0.5 GeV. The measured data were also fitted to equation 8 with the following results from the fitting:

$$\tau_e^N\,[h] = 0.2\,a^2 \qquad \textit{for } a \le 6.5\ mm$$

$$\tau_{others} = 8\ h$$

Once again the 6.5 mm limit, which is in good agreement with the results at 2.5 GeV is smaller than the expected limiting aperture. The factor 0.2 agrees with the theoretical calculation when using a pressure of 4.10^{-10} mbar, in good agreement with the measured one.

Touschek lifetime

In order to determine the Touschek contribution the lifetime has been measured as a function of bunch current for different RF voltages and tune settings. To this purpose 150 mA have been distributed over 25, 50, 75 and 100 bunches. Since the total current is the same for all the measurements the gas pressure and thus the gas lifetime should be the same. Its contribution to the lifetime has been considered constant and has been determined by a linear extrapolation to zero bunch current. The measurements were performed at 2.5 GeV and care was taken to ensure that the beam was longitudinally stable.

The Touschek lifetime is expected to be inversely proportional to the bunch current,

$$\frac{1}{\tau} = \frac{1}{\tau_T} + \frac{1}{\tau_{others}} = c_T i_B + \frac{1}{\tau_{others}} \qquad [9]$$

Figure 4 shows the measured inverse lifetime as a function of the bunch current, for an RF voltage of 1360 kV and for two different couplings.

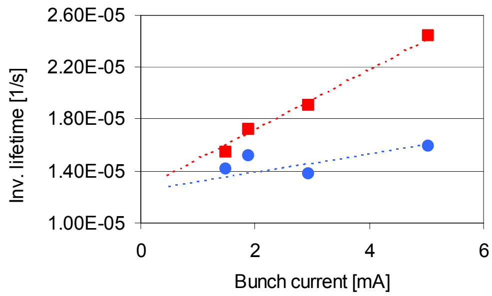

Figure 4: Inverse lifetime as a function of the bunch current, for 1.7 % (squares) , 2.7 % (circles) coupling

From Figure 4 the fitted Touschek is 60 h for 1.7 % coupling and almost 200 h. for the 2.7 % coupling for a current of 2 mA/bunch.

The increased coupling increases the vertical beam size by a factor 1.5 as observed on the synchrotron light monitor. If only the different beam size was responsible for the difference in Touscheck lifetime observed, then we would expect that the results for the 2.7 % coupling were a factor 1.5 larger than the results for the 1.7 % coupling situation. The Touscheck lifetime increases but by a factor 3.

Values of $c_T(V_{RF})$ and τ_{others} were determined by fitting equation 9 to measurements at different RF voltages. The value of τ_{others} have been assumed to be independent of the RF voltage, since the inelastic gas scattering shows only a weak dependence on it. Touschek lifetimes calculated from the fit for a current of 2mA/bunch as a function of the RF Voltage together with the theoretical predictions are given in Figure 5.

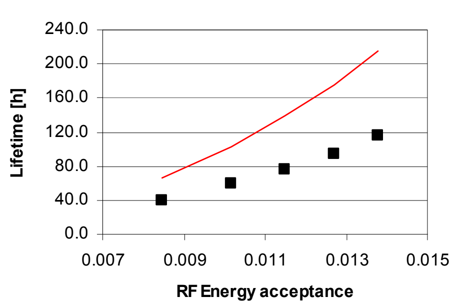

Figure 5: Touschek lifetime as a function of the RF energy acceptance for 2 mA/bunch and 1.7 % coupling

The differences point to an energy acceptance not limited by the RF voltage but by the dynamic aperture of the storage ring. Further studies are in progress in order to understand these results.

Lifetime versus Dose

The gas lifetime of the electron beam in a storage ring increases with the accumulated dose by which the vacuum system is cleaned. The increase of the lifetime for ANKA is shown in Figure 6.

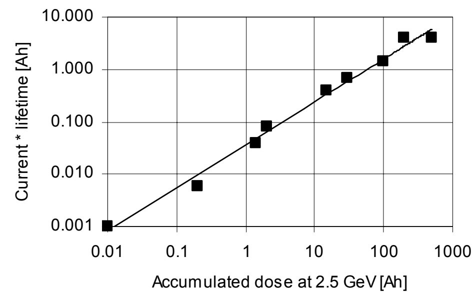

Figure 6: Lifetime times current as a function of the accumulated dose

SUMMARY

Beam lifetimes at the ANKA electron storage ring have been measured and the different components have been identified. Table 2 lists the different contributions for a 50 mA current [2 mA/bunch] with a RF energy acceptance of 1 % and a coupling of 1.7 %.

Table 2: The different contributions to the lifetime for a 50 mA current [2 mA/bunch] and a RF energy acceptance of 1 %

Lifetime	Measured [h]	Theory [h]
Elastic	54	62
Inelastic	68	40
Touschek	60	103
Total	20	20

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[3] A.-S.Müller, I.Birkel, E.Huttel, F.Perez, M.Pont and R.Rossmanith, these Proceedings