ELECTRON BEAM LIFETIME IN SOLARIS STORAGE RING

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Abstract

Solaris storage ring is a recently constructed and commissioned machine. At the beginning of storage ring operation the lifetime was very short mostly dominated by the ion trapping and residual gas scattering. After a 390 A·h of beam cleaning the measured total lifetime has reached 20 h for 100mA of a stored current. Since the main contribution to the total lifetime in the storage ring comes from single Coulomb and Touschek scattering the dependence of the residual gas pressure and the vertical aperture of storage ring is investigated. Moreover to improve the Touschek lifetime the 3rd harmonic cavities were installed. Recently the cavities were tuned close to the resonance and the total lifetime increased significantly. This presentation will report on the lifetime measurements and calculations carried out for Solaris 1.5 GeV storage ring at different vacuum and RF conditions.

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The total lifetime τ_{tot} in an electron storage ring containing N_e electrons is defined through the relative loss rate at a given time, according to the formula 1:

$$\frac{1}{\tau_{tot}} = -\frac{1}{N_e}\frac{dN_e}{dt}\,. \tag{1}$$

The contribution to the total lifetime has elastic $\tau_{elastic}$ and inelastic $\tau_{inelastic}$ scattering of the beam electrons on the atoms of the residual gas, the electron-electron scattering $\tau_{Touschek}$ within the bunch and the quantum excitation $\tau_{quantum}$.

$$\frac{1}{\tau_{tot}} = \frac{1}{\tau_{elastic}} + \frac{1}{\tau_{inelastic}} + \frac{1}{\tau_{Touschek}} + \frac{1}{\tau_{quantum}} \tag{2}$$

The Solaris storage ring is equipped with two vertical and one horizontal scraper which are used to determine the different lifetime limitations contributing to the total beam lifetime. In daily operation the scrapers are extracted far from the beam center and they do not limit the lifetime or the acceptance. The elastic scattering lifetime ($\tau_{elastic}$) contributed from electrons scattered on residual gas nuclei ($\tau_{elastic,nucl}$) and on the electrons in residual gas ($\tau_{elastic,elec}$). However, after gas nuclei analysis the lifetime from elastic scattering on the electrons can be neglected. Therefore, the vertical scraper mostly affects electrons that have been elastically scattered on residual gas nuclei:

$$\frac{1}{\tau_{elastic}} = \frac{1}{\tau_{elastic,elec}} + \frac{1}{\tau_{elastic,nucl}} \sim \frac{1}{\tau_{elastic,nucl}}\,. \tag{3}$$

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The elastic lifetime is given by [1,2]:

$$\frac{1}{\tau_{elastic}} = cn_g \frac{2\pi r_e^2 Z^2}{\gamma^2}\left[\frac{\beta_y\langle\beta_y\rangle}{a_y^2}\right], \tag{4}$$

where c is the speed of light, n_g is the residual gas density, r_e the classical electron radius, Z is the atomic number of the residual gas, γ is the relativistic factor of the electrons in the stored beam, $\langle\beta_y\rangle$ is the vertical beta function averaged over the storage ring, β_y is the vertical beta function at the limiting vertical aperture and a_y is the limiting vertical aperture. The inelastic scattering lifetime ($\tau_{inelastic}$) is usually expressed as [1,3]:

$$\frac{1}{\tau_{inelastic}} = \frac{1}{\tau_{inelastic,elec}} + \frac{1}{\tau_{inelastic,nucl}}, \tag{5}$$

what can be expanded using momentum compaction factor marked as α_c and momentum acceptance δ_{acc} to the forms [3]:

$$\frac{1}{\tau_{inelastic,elec}} = cn_g 4\alpha_c r_e^2 Z^2 \left\{ \ln\left(\frac{183}{\sqrt[3]{Z}}\right)\frac{4}{3}\cdot \left[\ln\left(\frac{1}{\delta_{acc}}\right) - \frac{5}{8}\right] + \frac{1}{9}\left[\ln\left(\frac{1}{\delta_{acc}}\right) - 1\right]\right\}, \tag{6}$$

$$\frac{1}{\tau_{inelastic,nucl}} = cn_g 4\alpha_c r_e^2 Z^2 \left\{ \ln\left(\frac{1194}{\sqrt[3]{Z^2}}\right)\frac{4}{3}\cdot \left[\ln\left(\frac{1}{\delta_{acc}}\right) - \frac{5}{8}\right] + \frac{1}{9}\left[\ln\left(\frac{1}{\delta_{acc}}\right) - 1\right]\right\}. \tag{7}$$

There is also a contribution to the total lifetime from Touschek scattering comming from electron-electron collisions inside the bunch. The Touschek lifetime is given by [1,4,5]:

$$\frac{1}{\tau_{Touschek}} = \frac{r_e^2 c N_b}{8\pi\gamma^3\sigma_z}\frac{1}{C}\oint \frac{F\left(\left[\frac{\delta_{acc}(s)}{\gamma\sigma_{x'}(s)}\right]^2\right)ds}{\sigma_x(s)\sigma_y(s)\sigma_{x'}(s)\delta_{acc}^2(s)} \tag{8}$$

where r_e is the classical electron radius, c is the speed of light, N_b is the number of electrons per bunch, γ is the relativistic factor of the electrons in the stored beam, σ_z is the bunch length, C is the circumference of the storage ring and $\sigma_x(s)$ is the horizontal beam size.

The quantum lifetime $\tau_{quantum}$ for a vertical aperture is given by [1,6]:

$$\frac{1}{\tau_{quantum}} = \tau_y \frac{\sigma_y^2}{a_y^2}\exp\left(\frac{a_y^2}{2\sigma_y^2}\right), \tag{9}$$

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where τ_y is the vertical damping time, σ_y is the vertical beam size at the limiting vertical aperture and a_y is the limiting vertical aperture. For the scrapers position far from the beam center, the quantum lifetime ($\tau_{quantum}$) is orders of magnitude greater than other lifetime components, so that quantum contribution can be neglected.

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The total lifetime in the storage ring is studied for different positions of upper and lower vertical scraper, respectively. Range of the stored current in each experiment is quite small so that there are no additionally current-dependent lifetime effects. Moreover, the measurements were done for two different configurations, one with stable working point where Landau cavities are tuned close to the flat potential condition with 3rd harmonics of main cavities frequency and second condition with Landau cavities detuned to the range where its influence on the beam is negligible.

The lifetime is shown as a function of the distance between the vertical scraper and the beam center. In the measurement the main RF voltage is kept constant at 410 kV. The stored current is around 200 mA.

Some of the Solaris storage ring parameters used in a beam lifetime computations are presented in Table 1.

Table 1: Solaris Storage Ring Parameters

Parameter	Value
Energy	1.5 GeV
Relativistic γ-factor	2935
Average $\langle\beta_y\rangle$	8.27 m
Vertical β-function β_y	3.63 m
Horizontal β-function β_x	5.73 m
Vertical beam size σ_y	13 µm
Momentum acceptance δ_{acc}	4%
Damping time τ_y	8.42 ms

The total lifetime in Solaris storage ring is determined by fitting an exponential function to the beam current measured with the DCCT. For a reliable lifetime measurement the beam current is monitored for 60 seconds after scraper motor reaches the desired position. Then each lifetime component can be extracted by fitting to the total lifetime following structure:

$$f(x) = \frac{\tau_{rest} A \min(x^2, a_0^2)}{\tau_{rest} + A \min(x^2, a_0^2)} \qquad (10)$$

where A is a parameter proportional to the elastic lifetime and τ_{rest} is a parameter for combined inelastic scattering and Touschek lifetime.

Figure 1 shows a measurement of the lifetime in Solaris in a stable working point as a function of the distance between the vertical scraper and the beam centre. Figure 2 describes similar measurement, but in this case Landau cavities have no influence on the beam.

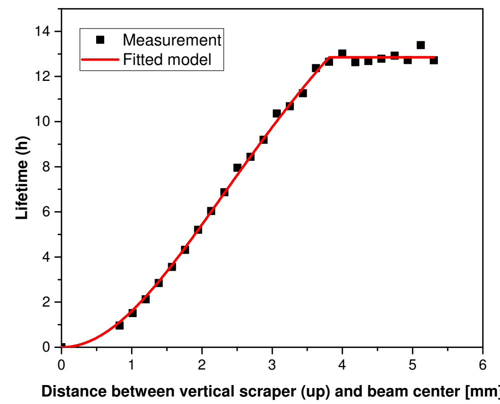

Figure 1: Lifetime vs. distance between the vertical scraper and the beam centre for tuned Landau cavities.

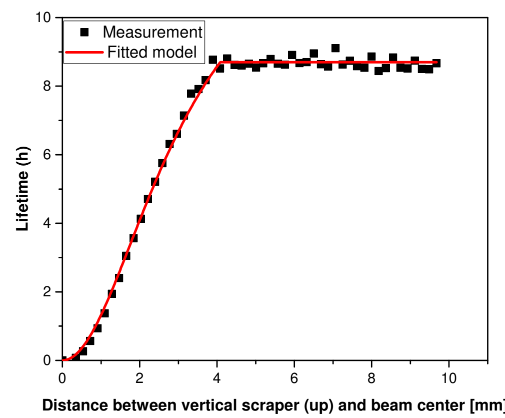

Figure 2: Lifetime vs. distance between the vertical scraper and the beam centre for detuned Landau cavities.

VACUUM CONDITION DURING THE MEASUREMENT

To evaluate residual gas composition in the storage ring Microvision 2 mass spectrometer with 3 meters extender from MKS was chosen. Device with factory calibration settings, accuracy level equal to 7, electronic gain and multiplier switched on allowed for qualitative measurement of partial pressure in dynamic range of 6 decades between $1{\cdot}10^{-7}$ and $1{\cdot}10^{-13}$ mbar [7]. Knowing the composition of the residual gas one can calculate inelastic and Touschek lifetimes from combined τ_{rest} fit parameter.

Table 2 presents the residual gas composition dominated by the hydrogen molecules. Computation results for lifetime contribution from the elastic, inelastic scattering and Touschek effect are presented in Tables 3 and 4 for Landau cavities detuned away from 3rd harmonic and close to the flat potential condition, respectively.

Harmonic cavities tuned to a working point increased significantly the Touschek lifetime. This is in a good agreement

Table 2: Relative Proportions of the Residual Gas Composition in Solaris

Gas	Rel. proportion
H_2	82.13%
CO_2	0.74%
CO	8.31%
CH_4	1.49%
CH_3	1.92%

Table 3: Lifetime Limitations in Solaris with 200 mA of Stored Beam with Landau Cavities Detuned

Component	Quantity
Elastic scattering $\tau_{elastic}$	22.24 h
Inelastic scattering $\tau_{inelastic}$	37.45 h
Touschek lifetime $\tau_{Touschek}$	21.13 h
Total lifetime τ_{tot}	8.41 h

Table 4: Lifetime Limitations in Solaris with 200 mA of Stored Beam with Landau Cavities Tuned

Component	Quantity
Elastic scattering $\tau_{elastic}$	23.66 h
Inelastic scattering $\tau_{inelastic}$	43.57 h
Touschek lifetime $\tau_{Touschek}$	68.81 h
Total lifetime τ_{tot}	12.54 h

with the theoretical predictions because bunch lengthening induced by Landau damping should increase an average distance between electrons inside the bunch, hence intra-bunch scattering should be lower.

DISCUSSION

The scrapers measurements in Solaris allowed to determine the lifetime limitation due to the elastic scattering on residual gas atoms in the vacuum system. The total lifetime in Solaris at the measurement with 200mA of stored beam at full energy of 1.5 GeV is 12.54 h. It is determined by the following lifetime limiting effects: elastic (23.66 h) and inelastic (43.57 h) scattering on the residual gas as well as Touschek effect (68.81 h).

Moreover, the measurement provides the quantities of vertical and horizontal acceptances. For the vertical plane the physical acceptance is 3.81 mm mrad, whereas for the horizontal plane the acceptance is 6.51 mm mrad. This informations are essential to determine quantities like minimal gap for Insertion Device (ID) vacuum chamber or minimal closing gap for in-vacuum ID.

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