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STUDIES OF THE ELECTRON BEAM LIFETIME IN SOLARIS ELECTRON STORAGE RING

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Abstract

Solaris storage ring is a recently constructed and commissioned machine operated in decay mode. With total accumulated beam dose near to 1000 Ah the measured total lifetime has reached 16 h for 270 mA of a stored current. In this paper, the beam lifetime studies are presented using measured residual gas analysis and vertical scraper position for tuned and detuned Landau cavities. It shows that for stable beam the lifetime is dominated by the interaction of the electron with residual gas (vacuum lifetime) and between electrons interaction within a bunch (Touschek lifetime). The estimated vacuum, Touschek and total beam lifetimes from theoretical analysis are also compared with the measured beam lifetime.

INTRODUCTION

For electron storage ring containing N_e electrons the electron beam lifetime τ_{tot} is defined as a relative loss rate at a given time, according to the formula:

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

In general the total lifetime in an electron storage ring is given by:

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

Where τ_{elastic} and $\tau_{\text{inelastic}}$ are components of the vacuum lifetime from elastic and inelastic scattering of the beam electrons on residual gas molecules and electrons in vacuum; Touschek lifetime τ_{Touschek} is a contribution from scaterring between electrons within a bunch, which leads to electron loss due to momentum transfer from transverse to longitudinal motion, whereas the quantum lifetime τ_{quantum} is related to the synchrotron radiation, and its contribution can be neglected for scraper position range used during these studies.

According to [1, 2] elastic lifetime is dominated by electron-nuclei scattering and electron-electron scattering could be neglected. Therefore the elastic lifetime is given by:

$$\frac{1}{\tau_{\text{elastic}}} = cn_g\frac{2\pi r_e^2 Z^2}{\gamma^2}\left[\frac{\beta_y\langle\beta_y\rangle}{a_y^2}\right] \tag{3}$$

Where c is the speed of light, n_g is the residual gas density, r_e is the classical electron radius, Z is the average 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.

Inelastic scattering lifetime consists of two components: electron-electron and electron-nuclei lifetimes.

$$\frac{1}{\tau_{\text{inelastic}}} = \frac{1}{\tau_{\text{inelastic,elec}}} + \frac{1}{\tau_{\text{inelastic,nucl}}} \tag{4}$$

The lifetime due to inelastic scattering on the residual gas electrons is given by:

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

Where α is the fine-structure constant and δ_{acc} is momentum acceptance.

The lifetime due to inelastic scattering on the residual gas nuclei is given by:

$$\frac{1}{\tau_{\text{inelastic,elec}}} = cn_g 4\alpha r_e^2 Z^2\left\{\ln\left(\frac{1194}{Z^{\frac{2}{3}}}\right)\cdot \frac{4}{3}\left[\ln\left(\frac{1}{\delta_{\text{acc}}}\right)-\frac{5}{8}\right]+\frac{1}{9}\left[\ln\left(\frac{1}{\delta_{\text{acc}}}\right)-1\right]\right\}. \tag{6}$$

Assuming that only elastic lifetime τ_{elastic} depends on the limiting vertical aperture a_y [3, 4] one can determine the lifetime components by measuring the total lifetime τ_{tot} as a function of the vertical scrapers position installed in the storage ring.

Fitting a formula (7) to the total lifetime function of an aperture a_0 sum of inelastic and Touschek lifetimes can be calculated from τ_{rest} parameter. Moreover, knowing an average atomic number Z of the residual gas from mass spectrometer measurements [5], the elastic lifetime can be calculated from A parameter.

$$f(x) = \frac{\tau_{\text{rest}} A \min(x^2, a_0^2)}{\tau_{\text{rest}} + A\min(x^2, a_0^2)} \tag{7}$$

LIFETIME MEASUREMENTS AND RESULTS

The Solaris storage ring is equipped with two vertical, one horizontal scraper and two Landau cavities. The measurements were done by using two vertical scrapers (up-down

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and down-up movement) for tuned and detned Landau cavities (LC). The lifetime was determined from the decay of electron beam current measured by a DC current transformer (DCCT). The time interval for single lifetime measurement was 60 s. The accuracy of the measurement depends on the accuracy of the DCCT and the time interval of the measurement. For those studies the measurement accuracy is estimated for less than 2%. Beam current was set to 250 mA and RF voltage to 480 kV, other useful parameters of Solaris storage ring are grouped together 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
Vertical beam size σ_y	13 μm
Momentum acceptance δ_{acc}	3.7 %
Vertical physical acceptance	3.45 μmrad
Horizontal physical acceptance	14.93μmrad
Electrons in storage ring (250 mA)	5×10^{11}
Electrons loss per second (20 h lifetime)	7×10^{6}
Energy lost per turn U_0	114 keV
Momentum compaction factor α_c	3.055×10^{-3}
Harmonic number	32

Figure 1 presents four separate measurements of the lifetime as a function of the distance between vertical scraper and the electron bunch centre. Two vertical scrapers were used. First – marked as VDOWN was moving from the top towards the centre, whereas the second scraper (VUP) was moving from the bottom. For both cases lifetime measurements were made with tuned and detuned LC. After fitting Eq.(7) to the measured data, individual components of the total lifetime are calculated. The results are presented in the Table 2.

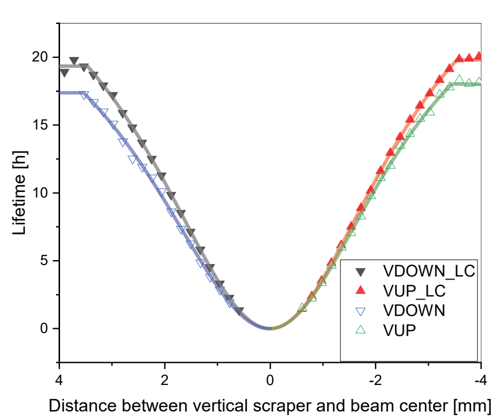

Figure 1: Total lifetime vs. distance between the vertical scraper and the beam centre.

Table 2: Lifetime Limitations in Solaris Storage Ring with 250 mA of Stored Current without and with Landau Cavities Tuned

Component	Without LC	With LC
Elastic scattering τ_{elastic}	45.03 h	50.54 h
Inelastic scattering τ_{inlastic}	91.92 h	101.37 h
Touschek lifetime τ_{Touschek}	42.64 h	47.67 h
Total lifetime τ_{tot}	17.64 h	19.74 h

The studies show that the Touschek lifetime is a slightly longer for the LC tuned with respect to the measurement without LC, which is related to the electron bunch lenghtening. However, the effect is not so prominent and can indicate that the Landau cavities are not tuned properly. This requires additional investigation and diagnostics, i.e. bunch length measuremnent and will be studied in next few months.

Moreover, the lifetime as a function of the RF gap voltage and the the VUP scraper position was studied. The measurement results with fitted Eq (7) are presented in Fig. 2. As seen, the total lifetime is decerasing when the RF gap voltage decreases. Since the RF gap voltage is related to the RF bucket height which defines the momentum acceptance for the entire ring, the Touschek lifetime will also decrease. Calculated components of total lifetime are shown in Fig. 3. For the low RF voltages the total lifetime is mostly dominated by the Touschek losses, which means that the vertical amplitude of the electron oscilations is higher than the RF bucket hight .

Solaris storage ring vacuum has reached over 1000 Ah of beam conditioning. Comparing the obtained lifetime componets with the studies done after 390Ah of the accumulated current [2] the total lifetime as well as its components are increased more than twice.

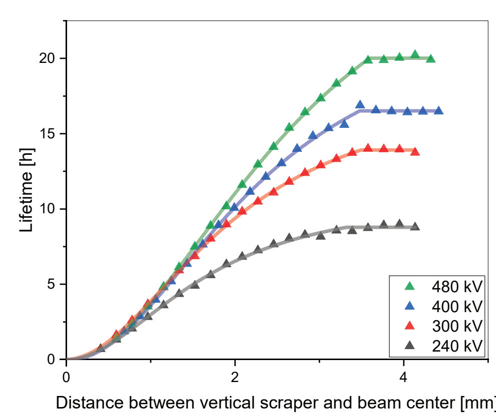

Figure 2: Total lifetime vs distance between vertical scraper and beam center for different RF voltage.

Figure 4 shows the lifetime, the average lattice and momentum acceptances vs RF gap voltage. For this measurement, starting point for beam current was 250 mA. With time and

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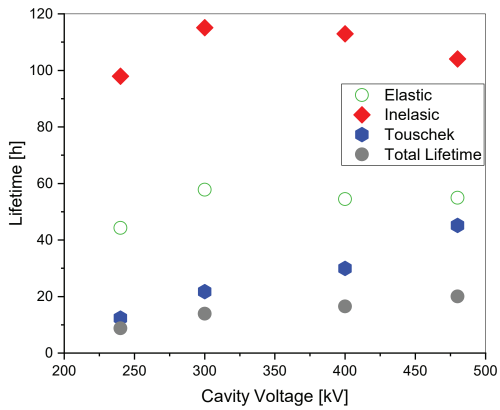

Figure 3: Total lifetime and its calculated components vs RF cavity voltage.

gradually reduced cavity voltage, beam current decreased. For this reason total lifetime was normalized to 250 mA beam current. At the moment, due to problems with RF circulator, measurements for higher cavity voltage were not possible. The RF momentum acceptance $\delta_{\rm acc}^{\rm RF}$ was calculated from the Eq. 8 which can be found in [1].

$$\delta_{acc}^{RF} = \sqrt{\frac{2U_0}{\pi\alpha_c h_{RF} E_0}\left[\sqrt{\frac{e^2V_0^2}{U_0^2}-1} - \arccos\left(\frac{U_0}{eV_0}\right)\right]} \quad (8)$$

Where U_0 is the energy loss per turn, α_c is the momentum compaction factor, $h_{\rm RF}$ is the harmonic number, E_0 is the nominal electron energy, e is elementary charge and V_0 is the RF cavity voltage.

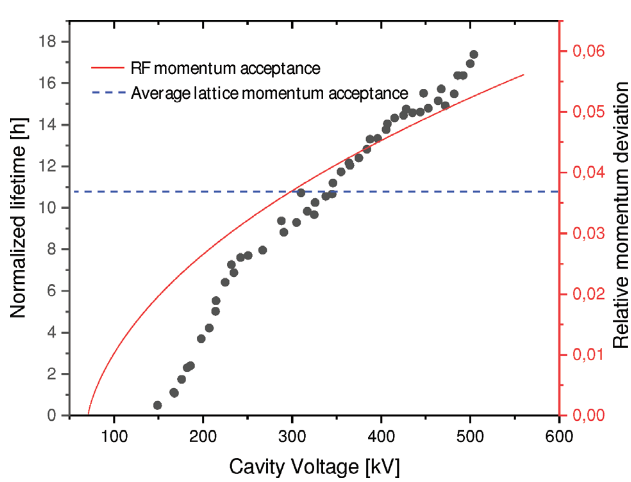

Figure 4: Normalized lifetime and momentum acceptance vs RF cavity voltage.

VACUUM CONDITIONS

To evaluate residual gas composition in the storage ring Microvision 2 mass spectrometer with 3 meters extender from MKS was used. Table 3 presents the residual gas composition dominated by the hydrogen molecules.

Table 3: Relative Proportions of the Residual Gas Composition in Solaris

Gas	Rel. proportion
H_2	84.04 %
CO_2	0.01 %
CO	3.10 %
CH_4	0.02 %
CH_3	0.01 %

CONCLUSIONS

The vertical scraper measurements in Solaris have contributed to determine the lifetime limitation due to the vacuum and Touschek components. The use of Landau cavities increased the total lifetime and its components, but only slightly. This indicates suboptimal tuning of cavities. The lifetime and its components dependence of RF cavity voltage showed that the lifetime decreasing with the RF gap volatge and for low voltages is mostly dominated by the Touschek lifetime. The calculated RF acceptance showes that below 280 V the lifetime mostly limited by the RF acceptance. More lifetime studies to be conducted in the near future to investigate the impact of the LC tuning on the Touschek lifetime and bunch lenght.

REFERENCES

[1] A.Hansson, "Electron beam sizes and lifetimes at MAX II and MAX III", Doctoral Thesis 2012.

[2] M.B. Jaglarz, *et al.*, "Electron Beam Lifetime in SOLARIS Storage Ring", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2731-2733. doi.org/10.18429/JACoW-IPAC2017-WEPAB067

[3] A. Hansson, *et al.*, "Electron beam stability and lifetime at the MAXIII synchrotron light source", ISBN: 978-91-7473-398-3, p. 174, Lund University, Sweden, 2012.

[4] A.Wrulich, "Single-beam lifetime", in proceedings of the 1992 CERN Accelerator School, Jyvaskyla, Finland pp. 409–435, CERN-94-01, 1994.

[5] A. M. Marendziak, S. Piela, M. J. Stankiewicz, A. I. Wawrzyniak, M. Zajac, and E. Al-Dmour, "Residual Gas in the Vacuum System of the Solaris 1.5GeV Electron Storage Ring", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2734–2737. doi:10.18429/JACoW-IPAC2017-WEPAB068