BEAM LIFETIME STUDIES FOR SPS STORAGE RING

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Abstract

Limitation of beam lifetime was systematically investigated and studied for Siam Photon Source (SPS) storage ring. The objective was to identify the main cause of the observed reduction of beam lifetime. The simulations of momentum acceptance and Touschek lifetime were performed, incorporating non-linear effects generated by the installed high-field insertion devices. The Touschek lifetime was measured as a function of RF voltage and compared with the values obtained from simulation. The measurements were performed for a variety of different operation conditions of the insertion devices and different chromaticities.

INTRODUCTION

The Siam Photon Source is a dedicated 1.2 GeV synchrotron light source. User operation is performed in beam decay mode with the maximum current of 150 mA. Beam lifetime can be varied in the range of 10-24 hours at 100 mA beam current. Beam injection is carried out twice a day, and each injection takes roughly 30 minutes. Figure 1 shows beam current in the SPS storage ring over 24 hours period during routine operation.

Beam lifetime in the SPS storage ring is limited by Touschek scattering and strongly depends on operation conditions, i.e. insertion devices, coupling, chromaticity and cavity voltage. In 2016, a 2nd RF cavity has been installed to increase the Touschek lifetime and compensate energy loss from high-field insertion devices. However, increasing the RF voltage does not improve the Touschek lifetime as expected. To identify the main cause of this limitation, studies of Touschek lifetime have been performed for a variety of different operation conditions of the insertion devices and different chromaticities. The results will be presented herewith.

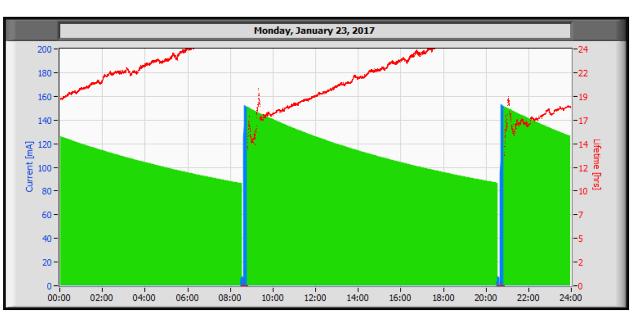

Figure 1: Daily SPS stored beam current.

TOUSCHEK LIFETIME SIMULATION

The Touschek effect is a loss mechanism driven by large angle Coulomb collisions in the electron bunch that lead to momentum transfers into the longitudinal plane. The change in the longitudinal momentum can lead to particle loss if the momentum exceeds the momentum acceptance. [2] In this simulation Touschek lifetime is computed using Piwinski's formula [1,2], implemented in Elegant code. This formula can be expressed by:

$$\frac{1}{\tau}=\left\langle \frac{r_0^2 c N_b}{8\pi\gamma^2\sigma_s\sqrt{\sigma_x^2\sigma_y^2-\sigma_p^4 D_x^2 D_y^2}\,\tau_m} F(\tau_m,B_1,B_2)\right\rangle \quad (1)$$

with

$$F(\tau_m,B_1,B_2)=\sqrt{\pi(B_1^2-B_2^2)}\,\tau_m\int_{\tau_m}^{\infty}\left[\left(2+\frac{1}{\tau}\right)^2\left(\frac{\tau/\tau_m}{1+\tau}-1\right)+1 -\frac{\sqrt{1+\tau}}{\sqrt{\tau/\tau_m}}-\frac{1}{2\tau}\left(4+\frac{1}{\tau}\right)\ln\frac{\tau/\tau_m}{1+\tau}\right]e^{-B1\tau}I_0(B_{2\tau})-\frac{\sqrt{\tau}d\tau}{\sqrt{1+\tau}} \quad (2)$$

where N_b is the number of electrons per bunch, σ_p is the energy spread, σ_s is the bunch length, D_x and D_y are the dispersion functions, σ_x and σ_y are the beam sizes, I_0 is the modified Bessel function and the functions B_1 and B_2 are given by

$$B_1=\frac{B_x^2}{2\beta^2\gamma^2\sigma_{x\beta}^2}\left(1-\frac{\sigma_h^2\tilde{D}_x^2}{\sigma_{x\beta}^2}\right)+\frac{\beta_y^2}{2\beta^2\gamma^2\sigma_{y\beta}^2}\left(1-\frac{\sigma_h^2\tilde{D}_y^2}{\sigma_{y\beta}^2}\right), \quad (3)$$

$$B_2^2=B_1^2-\frac{\beta_x^2\beta_y^2\sigma_h^2}{\beta^4\gamma^4\sigma_{x\beta}^4\sigma_{y\beta}^4\sigma_p^2}\left(\sigma_x^2\sigma_y^2-\sigma_p^4D_x^2D_y^2\right). \quad (4)$$

Momentum Acceptance

The Touschek lifetime strongly depends on momentum acceptance (MA) which is determined from the minimum of RF acceptance or transverse (physical or dynamic) momentum acceptance. In the SPS storage ring, RF momentum acceptance is one of the important issue. The RF system has been upgraded to provide sufficient lifetime after the installation of 6.5 T Superconducting Wavelength Shifter (SWLS) and 2.2 T Multipole Wiggler (MPW). The new RF cavity with the maximum cavity voltage of 300 kV increases the RF acceptance to 1.37%, which is 2.4 times higher than the previous one. The overvoltage factor is also increased from 1.58 to 3.79. Figure 2 shows the simulated RF acceptance together with the bunch length as a function of RF voltage.

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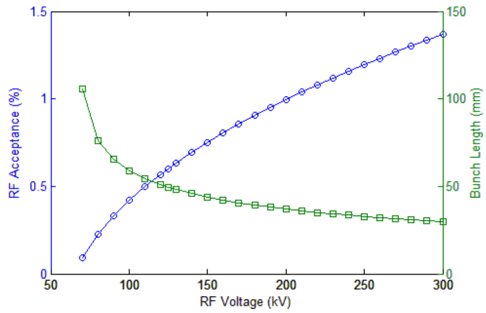

Figure 2: The simulated RF acceptance and bunch length as a function of RF voltage.

In order to determine the limitation of MA, the dynamic aperture including nonlinear effects generated by SWLS and MPW was investigated. (Fig. 3) Significant reduction in dynamic aperture is caused by magnetic field roll-off arising from the narrow pole width of the MPW. The dynamic aperture is reduced by more than 75% and 15% due to the MPW and SWLS, respectively [3-4]. This is the main cause of the MA limitation, especially when the RF voltage is high.

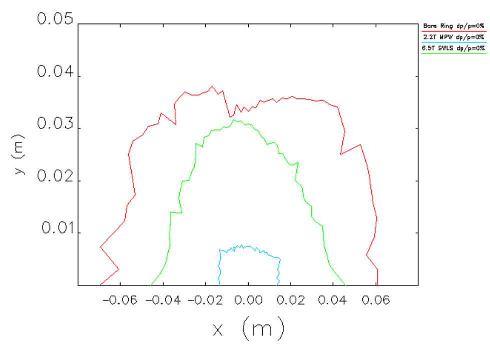

Figure 3: Comparison of dynamic apertures for different insertion devices.

MA at all the locations along the ring was simulated by particle tracking using Elegant code. Fig. 4 and Fig. 5 show the simulated MA for different voltages for the SWLS and MPW, respectively. It can be clearly seen that the MA in the dispersive region is strongly dominated by nonlinear dynamics produced by IDs. The limitation of MA wad observed at 125 kV for MPW and 210 kV for SWLS.

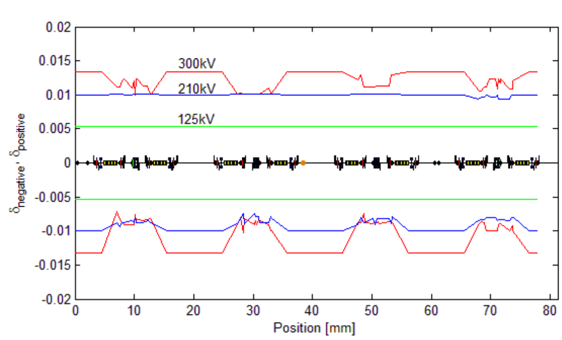

Figure 4: Momentum acceptance when the 6.5T SWLS is in operation.

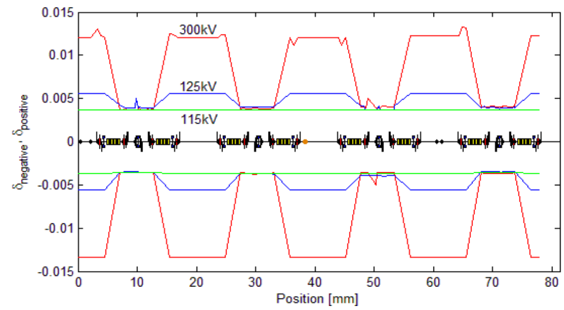

Figure 5: Momentum acceptance when the 2.2 T MPW is in operation.

TOUSCHEK LIFETIME MEASUREMENT

Effects of Insertion Devices

The effects of each insertion device on the Touschek lifetime were simulated and measured separately as a function of RF voltage. The result is shown in Fig. 6. The simulated Touschek lifetime is found to be higher than the measured value but they correlate quite well. Strong saturation of beam lifetime was found when the MPW is in operation, as predicted by simulation. There is no gain in lifetime above the RF voltage of 130kV in case of MPW (red line). For SWLS, the saturation was not reached even at 200 kV (green line). The cavity voltage was not increased beyond 200 kV due to multipacting issue of the new RF cavity.

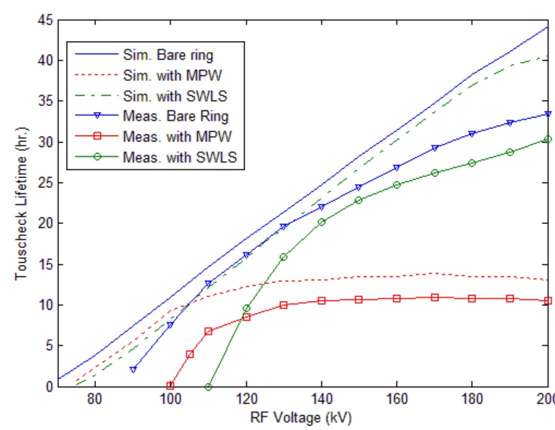

Figure 6: Comparison of simulated and measured Touschek lifetimes as a function of RF voltage for different operation conditions of the insertion devices.

Effect of Chromaticity

Touschek lifetime for different values of chromaticity was measured as shown in Fig 7. These measurements were performed with both MPW and SWLS operated at the maximum field, coupling adjusted to 8%, and electron beam current filled to about 1 mA per bunch. The nominal chromaticities of ξ_x =3 and ξ_y =3 (green line) are used for SPS storage ring in multibunch mode of operation. After the installation of MPW and SWLS, chromaticities changed to ξ_x =3.6 and ξ_y =6.3 (red line). By

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reducing the chromaticities to ξ_x =1 and ξ_y =1 (blue line), the measured Touschek lifetime was improved by about 17%.

The Touschek lifetime at high voltage is typically reduced by large chromaticity because it generates a wide tune spread of beam halo which leads to particle loss at low order resonance, as observed for example at ALS [5]. However, in the case of SPS storage ring, the Touschek lifetime is not strongly sensitive to chromaticity. This is probably due to the fact that the nonlinear effects generated by the MPW and SWLS are more adverse.

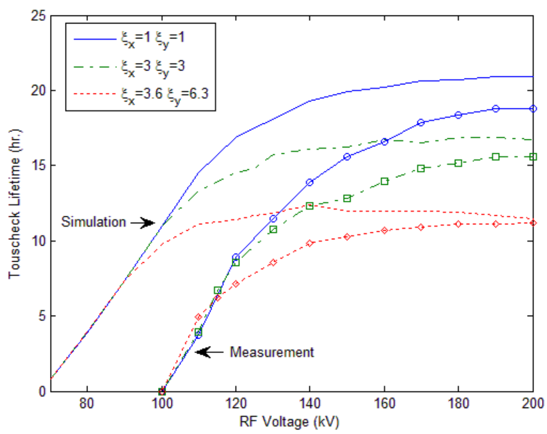

Figure 7: Comparison of simulated and measured Touschek lifetimes as a function of RF voltage for three different set of chromaticities.

One interesting result is shown in Fig. 7. We found that significant lifetime drop occurs when the RF voltage is decreased below 100kV, which disagrees with the simulation. However, the simulation and measurement agree quite well if ~30 kV of RF voltage is subtracted from the measurement. This indicates that quite possibly there is an offset between the actual voltage and the setting value. Future studies will be needed to indentify the cause of this offset.

Effect of Coupling

Effect of coupling on the Touschek lifetime was studied for the case of no IDs. The RF voltage was 125 kV. The chromaticity was set to +3 in both horizontal and vertical directions. The coupling was controlled by introducing vertical orbit at the sextupole magnets and was varied from 1% to 20%. Measured and simulated results agree quite well as shown in Fig. 8. The coupling which provide beam lifetime of 10 hours is chosen for user operation.

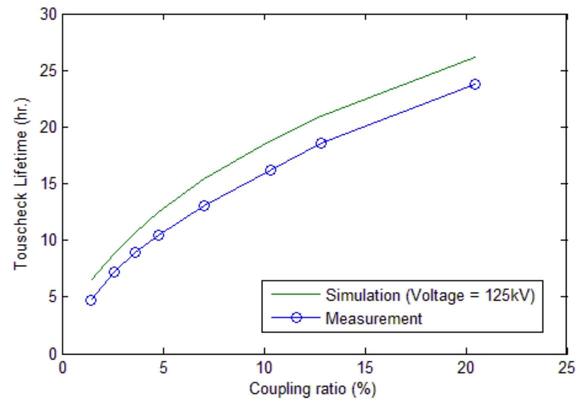

Figure 8: Comparison of the simulated and measured Touschek lifetimes as a function of coupling ratio.

CONCLUSION

Limitation of beam lifetime in SPS storage ring was carefully studied. The increase of RF cavity does not improve the Touschek lifetime due to nonlinear effects generated by IDs. These effects were clearly observed in the measurements as well as in the simulations. The Touschek lifetime could be improved by adjusting the chromaticities, and, in the future, by minimizing nonlinear dynamics through the use of magic fingers.

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