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IMPROVEMENT OF TOUSCHEK LIFETIME BY HIGHER HARMONIC RF CAVITY IN THE SPS STORAGE RING

T. Phimsen†, N. Juntong, P. Sudmuang,
Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand
Z. T. Zhao, B. C. Jiang, Shanghai Advanced Research Institute, Shanghai, China

Abstract

Siam Photon Source (SPS), located at Nakhon Ratchasima, Thailand, is a synchrotron light source with the beam energy of 1.2 GeV. User operation is performed in beam decay mode with the maximum current of 150 mA. Beam lifetime is about 12 hours at the beam current of 100 mA. Beam injection is carried out twice a day, and even with full energy, it takes roughly 30 minutes. Beam lifetime in the SPS storage ring is limited by Touschek scattering and strongly depends on operation conditions. Higher harmonic RF cavity is a proven method to increase the beam lifetime and suppressing coupled bunch instabilities through Landau damping effect. If the beam lifetime is increased for examples, to be double, only one injection per day would be needed. In this study, an improvement of Touschek lifetime by passive harmonic RF cavity is investigated.

INTRODUCTION

Siam Photon Source, located at Nakhon Ratchasima, Thailand, is a synchrotron light source with the beam energy of 1.2 GeV. The SPS parameters are shown in Table 1. 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 the beam current of 150 mA. 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 [1].

Beam lifetime in the SPS storage ring is limited by Touschek scattering and resolutely depends on operation conditions, for examples, insertion devices, coupling, chromaticity and cavity voltage.

In 2016, a 2nd RF cavity has been installed to solve the Touschek lifetime problem and compensate energy loss from high-field insertion devices. However, because of nonlinear effects generated by insertion devices, Touschek lifetime is still not improved by increasing RF voltage. These effects were clearly observed in the measurements as well as in the simulations [1].

Bunch lengthening using a higher harmonic RF cavity not only can improve the beam lifetime by suppressing the Touschek effect caused by the elastic scattering of electrons within the bunch [2, 3] but also can suppress coupled bunch instabilities as well as single bunch instabilities through Landau damping causing by increasing of synchrotron frequency spread [2, 4, 5].

† thanapong@slri.or.th

Table 1: SPS Main Parameters

Parameters	Value
Beam energy (GeV)	1.2
Circumference (m)	81.3
Stored beam current (mA)	150.0
Lattice	DBA
Superperiod	4
Max RF voltage, V_{RF} (kV)	250
RF frequency, f_{RF} (MHz)	118.0
Harmonic number	32
Energy loss per turn (keV)	65.94

In passive mode operation, a harmonic RF voltage is induced by beam current itself. Therefore, an external RF power source is not required, which makes it compact and economic. However, the bunch lengthening effect can be affected by fluctuation of the beam current. The passive cavities were widely used in many light sources around the world [6-9]. Besides, there is a study to improve the performance of passive harmonic using active feed forward technique to compensate the fluctuation of the RF voltage over a fill [10].

In this report, the bunch lengthening effect of harmonic cavity in SPS storage ring is investigated using analytical method based on the passive operation.

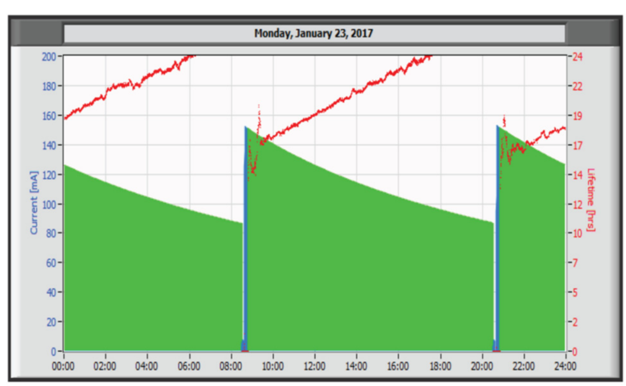

Figure 1: Daily SPS stored beam current.

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ANALYSIS ON HARMONIC CAVITY IN SPS STORAGE RING

In the passive operation that a harmonic cavity voltage is generated from the beam itself. The total voltage seen by the beam can be defined by Eq. (1) [11]

$$V(\tau)=V_{rf}\sin(\phi_s-\omega_{rf}\tau)-2I_bFR_s\cos\psi_h\cos(\psi_h-n\omega_{rf}\tau), \quad (1)$$

where, τ is the relative time deviation, V_{rf} is the main RF voltage, φ_s is the synchronous phase of the main RF cavity, ω_{rf} is the angular frequency, I_b is beam current, R_s is the shunt impedance; ψ_h is detuning angle of the harmonic cavity; n is the harmonic number, and F is the bunch form factor given by [11]

$$F=\exp[-(n\omega_{rf}\sigma_\tau)^2] \quad (2)$$

where σ_τ is the RMS bunch length; According to Eq. (1), the phase of harmonic voltage and the amplitude are related to detuning angle. The operating parameters in Eq. (1), have been optimized to obtain the flatten potential well for each harmonic frequency.

Table 2: Optimized Parameters of Passive Harmonic Cavity for SPS Storage Ring

Harmonic	Frequency (MHz)	ϕ_s (rad)	ψ_h (rad)	R_s (MΩ)
3rd	354	0.30	1.67	2.77
4th	472	0.28	1.64	3.09
5th	590	0.28	1.63	3.39

With the parameters shown in Table 2 the total RF voltage for each harmonic frequency can be found from Eq. (1). The result is shown in Figure 2. It is obvious that the range of zero slope voltage for the third harmonic one is longer than those of fourth and fifth harmonic. The potential and charge distribution calculated from the potential from different harmonic frequencies are shown in Figure 3.

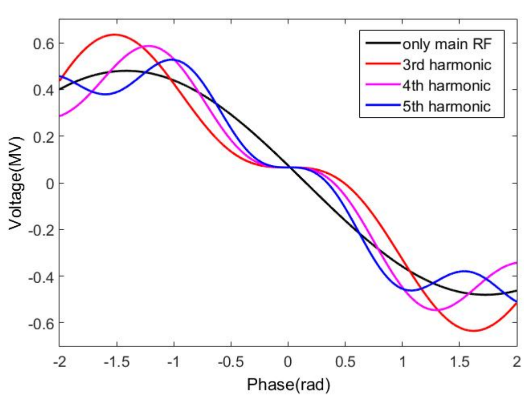

Figure 2: The total RF voltage.

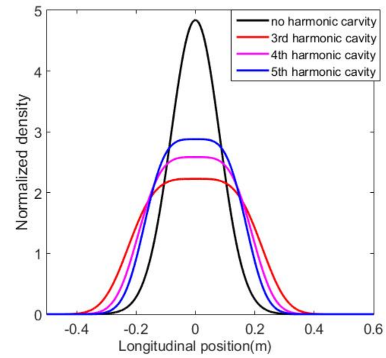

Figure 3: Normalized charge distribution for each harmonic frequency in SPS case.

LIFETIME IMPROVEMENT FACTOR

Figure 4 shows Touschek lifetime improvement factor calculated by a ratio of the lifetimes with and without harmonic voltage compared to harmonic voltage needed to get the flatten potential for each harmonic frequency operation. The third harmonic cavity can give the highest lifetime improvement factor of 2.22, while the improvement factor of fourth and fifth harmonic cavity are 1.54 and 1.36 respectively. The required harmonic voltage of 0.16 MV for the third harmonic cavity is not much higher than those of 0.12 MV and 0.10 MV in fourth and fifth harmonic cases, respectively. For SPS, passive normal-conducting cavity at third harmonic could provide this harmonic voltage but there are other aspects to consider such as the limitation of space and economy.

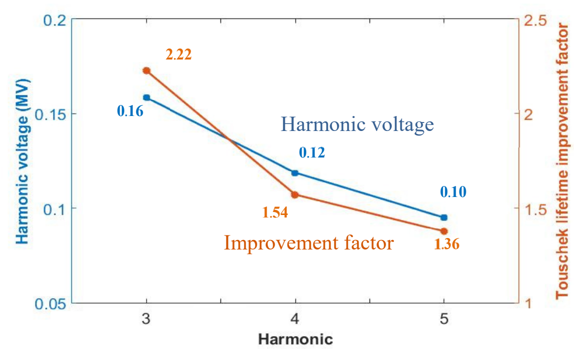

Figure 4: Lifetime improvement factor of each harmonic frequency compared to harmonic voltage needed to get the flatten potential.

According to Eq. (1), detuning angle is an important factor for the passive operation. The operating scheme of passive harmonic cavity can be simplified as two types. The former is fixed detuning and the latter is fixed harmonic voltage. For the fixed detuning operation, because the tuning plunger of higher harmonic cavity is fixed, it simplifies the operation of harmonic cavity, avoids using the RF feedback systems and increases the reliability of the system. On the other hand, one disadvantage of this scheme is that the bunch would have overstretched distribution when the machine operates in a higher beam current. And the bunch

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lengthening effect is reduced when the beam current is lower than the condition.

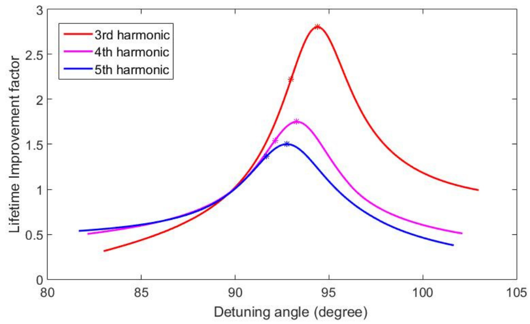

Figure 5: Lifetime improvement factor provided by harmonic cavity at different harmonic frequency and different detuning angle.

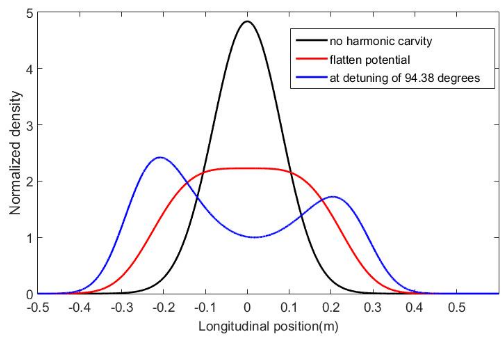

Figure 6: Normalized charge distribution in the third harmonic cavity case at flattens potential condition and at detuning angle of 94.38 degrees.

For the fixed voltage operation, the tuner system is needed to keep a fixed harmonic voltage to compensate the effect from a change of the operating currents. This operating scheme can reduce the change on the bunch shape and the lifetime improvement factor is relatively higher than that in fixed detuning case. Figure 5 shows an influence of detuning angle to the lifetime improvement factor provided by harmonic cavity at each harmonic frequency. The lifetime improvement can reach the highest factor of 2.80 in the third harmonic case at the detuning angle of 94.38 degrees. It is about 27% higher than that in flatten potential case. At this point, the particle density distribution is in overstretch condition as shows in Figure 6. The lifetime improvement factor in this case is much higher nearly twice of the highest factor of 1.8 and 1.5 in fourth and fifth harmonic case respectively. Considering fourth harmonic cavity case, the highest lifetime improvement factor of 1.75 at the detuning angle of 93.27 degrees is 14% higher than the improvement factor of flatten potential case. While, in fifth harmonic case, the maximum lifetime improvement factor at the detuning angle of 92.75 degrees reaches the factor of 1.50, which is about, 10% higher than the lifetime improvement factor in flatten potential condition.

However, in this study, the analytical model considered only in the case of a symmetric storage ring fill pattern and does not account for the transient effects of the double RF system. Besides, the influence of lengthened bunch on the passive harmonic cavity operation was also neglected. Both of these effects could significantly limit the performance of harmonic cavity and should be studied further [10,12-14].

CONCLUSION

The application of harmonic cavity to increase the beam lifetime in the SPS storage ring is investigated for the third harmonic, fourth harmonic and fifth harmonic cases. The third harmonic cavity shows its advantage of the highest improvement factor. But if there is a limitation of the space, the fourth or fifth harmonic cavity can be the alternative option.

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