BEAM LIFETIME STUDIES OF HEFEI ADVANCED LIGHT SOURCE (HALS) STORAGE RING*

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Abstract

Hefei Advanced Light Source (HALS) will be a high brightness light source with about 0.2nmrad emittance at 1.5GeV. Ultra low beam emittance and relatively low beam energy of HALS would result in poor beam lifetime. Comparing the beam-gas scattering and Touschek scattering effects, a conclusion can be drawn that Beam lifetime will be affected strongly by Touschek scattering. Touschek lifetime has been studied considering linear and nonlinear effects for the lattice structure. Relations between lifetime and RF cavity voltage, lifetime and emittance coupling, lifetime and gap heights of insertion devices have been calculated respectively. After the optimization, proper cavity voltage and emittance coupling are chosen to get about 1.06 hours of total lifetime including gas scattering losses effect. Installing a third harmonic RF cavity can lengthen the beam bunch to increase the total lifetime to about 3.85 hours. Top up injection operation will be applied to keep bunch current within the required value.

INTRODUCTION

Hefei Light Source (HLS) of National Synchrotron Radiation Laboratory is a dedicated second generation light source. In order to obtained synchrotron radiation with high brightness and better coherence in the VUV and soft X-ray range for synchrotron radiation users, A plane of building a new machine named HALS storage ring has been brought forward. Considering the required low emittance and the straight lines' number and length, A FBA lattice structure with 18 super-periods has been chosen for HALS. Figure 1 shows the β and dispersion functions of one cell, from which we can see there is not dispersion in straight sections. Main parameters about HALS storage ring can be founded in table1. Undulators' full gap heights is 8mm in order to obtain high brightness synchrotron radiation.

High brightness requires lower horizontal and vertical beam emittance and large beam current, which will result in small bunch volume and high current density in every bunch. Collisions of electrons in the bunch will become stronger. For the HALS lattice mode studied here, Touschek scattering is the main factor which will restrict the beam lifetime.

As we know, Touschek lifetime is in direct proportion to the square of momentum acceptance (MA) and to the bunch volume. It is an effective method to increase the MA or bunch volum (length) to get longer beam lifetime.

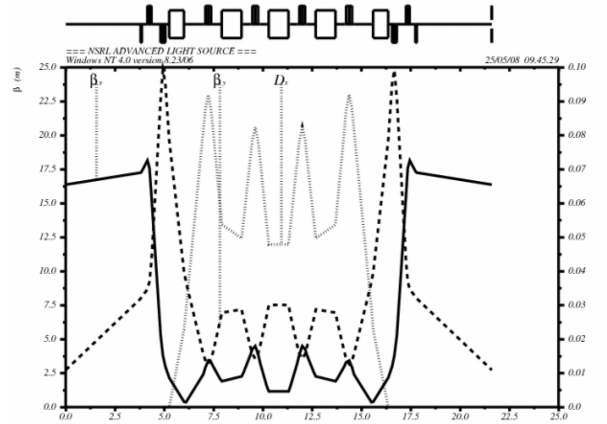

Figure 1: βand dispersion functions of one cell.

Table 1: Main Parameters of HALS Storage Ring

Parameters	Values
Circumference	388m
Energy	1.5GeV
Lattice structure	FBA
Super-period number	18
Straight section length	7.6m
Emittance of bare lattice	0.27 nm·rad
Emittance with damping Wigglers	<0.20 nm·rad
Transverse tunes	29.32/10.28
Natural chromaticities	-55/-51
Momentum compaction factor	0.00047
Energy spread	0.00022
Harmonic number	648

The RF bucket MA can be given as a function of cavity voltage and is invariable along the lattice structure. Another restriction is the lattice MA which is determined by physical aperture or dynamic aperture. Because the lattice MA depends on the scattering locations, it is not a constant along the lattice and it can be given as[1, 2]

$$\delta_{\mathrm{acc}}^{\mathrm{L}}(\mathrm{s}_0) = \min_{\mathrm{i}=1\ldots\mathrm{N}} \left\{ \frac{a_{\mathrm{xi}}}{\sqrt{H_0 \beta_{\mathrm{xi}}} + \eta_{\mathrm{i}}} \right\}$$

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with $\delta = \Delta p/p_0$, H_0 is Courant-Snyder invariant at s_0 where scattering occurred, $\beta_{xi}, \eta_i, a_{xi}$ corresponding horizontal beta function, dispersion and vacuum chamber's half width respectively. The above equation can be satisfied for a perfectly linear and chromaticity corrected lattice.

As to high brightness light source, in order to get lower emittance, strong quadrupoles must be required. large chromaticities generated by focusing should be corrected by strong sextupoles. In this way, Besides the linear effect to lattice MA, i.e. momentum dependency of linear lattice parameters, it is necessary to consider the nonlinearities[1-3] when calculating MA for HALS. First, nonlinearities can distort the transverse linear ellipse. When a Touschek scattered particle oscillates around the off momentum orbit, it may be not accepted by the nonlinear ellipse. Second, it can make the dynamic aperture depended on momentum become smaller than the physical aperture. Third, high order dispersion can make the relation of beam closed orbit to momentum nonlinear. Further more, considering synchrotron oscillation, a tune large spread generated by high order chromaticity can make some particles crossing several resonances. All of these will lead to reducing the lattice MA.

Some calculations for beam lifetime are presented in the next section. Tracking has been done for 300 turns. 500MHz RF frequency and 1.4nC charge per bunch are used for calculating the MA.

BEAM LIFETIME CALCULATION

Touschek lifetime and emittance coupling

Considering elements's misalignments and tilt errors in the ring, nonzero emittance coupling factor $\kappa = \varepsilon_y/\varepsilon_x$ will be generated. The average coupling 0.3% has been obtained without any coupling correction. Assuming RF cavity voltage is 1.5MV, one can get the Touschek lifetime of 0.38 hours with 0.3% coupling. It is obviously too short to use. One method to get a longer lifetime is to increase the emittance coupling by using skew quadrupoles. Figure 2 shows the Touschek lifetime with cavity voltage 1.5MV, as a function of coupling factor. When $\kappa \leq 70\%$, Touschek lifetime[7-8] is in proportion to $\sqrt{\kappa}$ approximately. The beam lifetime from κ =0.7 to 1.0 is restricted by vertical physical aperture. Finally 10% emittance coupling has been chosen to obtain a proper lifetime. Because the horizontal emittance of bare lattice is about 0.27nmrad, vertical emittance is low enough for giving high brightness radiation.

Touschek lifetime and RF cavity voltage[4-5]

Figure 3 displays the Touschek lifetime with 10% emittance coupling, as a function of cavity voltage. One can see that lifetime considering lattice nonlinearities is shorter than only considering linearity when the voltage is higher than 900kV. The Figure also shows bunch length and RF MA varying with cavity voltage. All of these two factors can affect the beam lifetime but in opposite directions. In order to use RF power effectively, cavity voltage of 1.2MV has been selected. In this condition, the touschek lifetime is 2.151 hours and RF MA is 3.984%. Synchrotron oscillation has been included during the calculation. Insertion devices' gap heights have not been set.

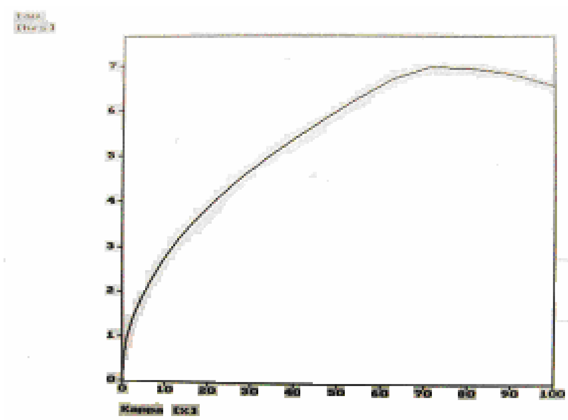

Figure 2: Touschek lifetime and emittance coupling with RF voltage 1.5MV

Touschek lifetime and Undulator gap heights

The beam halo usually has larger coupling than beam core, because larger amplitude particles are easy to cross high order coupling resonances[1, 6]. This properties will limited the touschek lifetime when using insertion devices with small full gap heights. Figure 4 shows the relation between the Touschek lifetime and the half gap heights with 1.2MV. Solid line displays the relation between touschek lifetime and gap heights for assuming 100% beam halo coupling. In this condition, lifetime would be reduced for gap heights smaller than 10mm. Dash line shows the lifetime with 10% beam core coupling and 10% beam halo coupling, which is not effected by the gap heights. In fact, the beam halo coupling is smaller than 100% but larger than the core coupling. Touschek lifetime is estimated as 1.1 hours with 4mm half gap heights.

Gas scattering lifetime

Electrons's scattering on gas molecules is another limitation to beam lifetime. With mini gap height of 4mm, β_y=3.5m at middle point of straight sections and $\langle\beta_y\rangle$=7.87m, assuming 1n Torr of carbon monoxide for the residual gas, the gas scattering lifetime is about 30.9 hours including elastic and unelastic scattering effects.

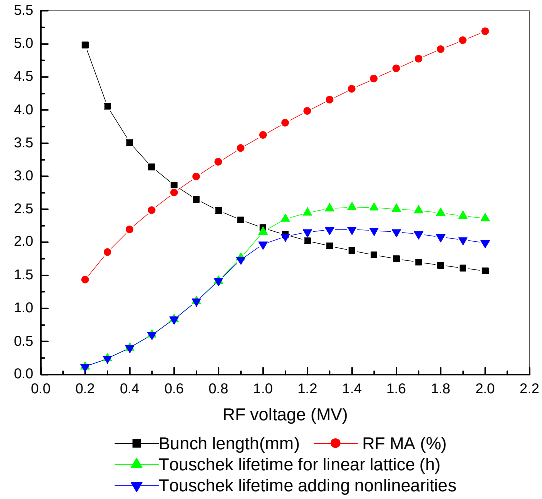

Figure 3: Bunch length, RF MA, Touschek lifetime with linearity and with nonlinearities, & RF voltage.

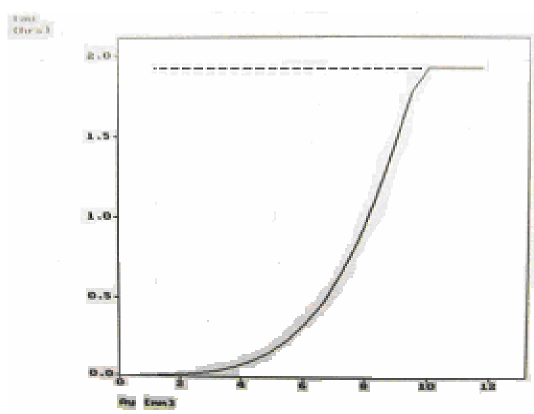

Figure 4: Relation between Touschek lifetime and half gap heights of undulators

Third harmonic cavity

Installing a third harmonic cavity[9-10] is one of the effective methods to increase the Touschek lifetime, which can lengthen the bunch to get a larger beam volume. Ideally, the touschek lifetime can be increase by a factor of 4 with the third harmonic cavity working. In this way, the beam lifetimes have been displayed in table 2 with considering 8mm full gap heights undulators. Top up injection operation will be applied to keep bunch current within the required value.

CONCLUSION

Touschek lifetime calculations have been presented considering lattice's linear and nonlinear effects. The dependency of lifetime on the RF cavity voltage and on the emittance coupling and on the full gap heights of insertion devices are studied for HALS storage ring lattice. About 1.06 hours Touschek lifetime has been obtained. Gas scattering lifetime is longer enough comparing with the Touschek lifetime. The total lifetime can be increased to 3.85 hours by installing the third harmonic cavity. Top up injection operation will be required to keep bunch current within the satisfied value.

Table 2: Beam lifetimes without and with the third harmonic cavity

	Touschek Lifetime (hours)	Gas Scattering (hours)	Total Lifetime (hours)
Without 3rd harm. cavity	1.1	~30.9	1.06
With 3rd harm. cavity	4.4	~30.9	3.85

REFERENCES

[1] M. Böge, A. Streum, "BEAM LIFETIME STUDIES FOR THE SLS STORAGE RING", PAC1999, New York1999, p:2430

[2] A. Nadji, G. Flynn, "ENERGY ACCEPTANCE AND TOUSCHEK LIFETIME CALCULATIONS FOR THE SOLEIL PROJECT", PAC1997, p:1517

[3] C. Montag, J. Bengtsson, "TOUSCHEK LIFETIME CALCULATIONS AND SIMULATION FOR NSLS-II", PAC2007, p:4375

[4] S. Guiducci, "BEAM LIFETIME STUDIES IN DAΦNE", EPAC 2002, p:1133

[5] A. Streun, "Beam Lifetime of the SLS Storage Ring", SLSTME-TA-2001-0191 (2001)

[6] T. Shaftan et al, "Control of Dynamic Aperture with Insertion Devices", EPAC 2006, p:3491

[7] F. Wang , "Touschek Lifetime Calculations for the NSLS-II Electron Storage Ring", MIT-Bates Internal Report , B/SHR-2006-1

[8] F. Wang, W. Franklin, et al, "Intrabeam scattering and Touschek lifetime for the optical stochastic cooling experiment at the MIT-bates south hall ring", PAC07, Albuquerque, New Mexico, USA,2007,P:4279

[9] N.P. Abreu, O. Bagnato, et al, "Conceptual design of A 3rd Harmonic cavity system for the LNLS Electron storage ring", EPAC 2006, Edinburgh, Scotland, P:1316

[10] David Alesini, "Third harmonic cavity design and RF measurements for the Frascati DA_NE collider", PHYSICAL REVIEW SPECIAL TOPICS – ACC. AND BEAMS,VOLUME **7**, 092001 (2004), 092001.