BEAM LIFETIME ESTIMATION FOR TAIWAN 3GEV SYNCHROTRON LIGHT SOURCE

W. T. Liu, H. P. Chang, H. C. Chao, P. J. Chou, C. C. Kuo, G. H. Luo, H. J. Tsai, and M. H. Wang

National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan

Abstract

The demanding design features of Taiwan Photon Source (TPS), low emittance and small gap undulator vacuum vessels, cause Touschek scattering and gas scattering to play a major limitation role for beam lifetime. We calculate the Touschek lifetime based on the tracking procedure determining energy acceptance. The nonlinear synchrotron oscillation due to large second-order momentum compaction factor is included in the energy acceptance calculations. Small vertical ID gaps are imposed in the tracking procedure. Besides, the gas scattering lifetime is estimated with varying gas pressure. The possible improvement solutions for lifetime will be addressed.

INTRODUCTION

Two kinds of lattice are developed during TPS lattice design process, which are Double-Bend Achromat (DBA) and Quadruple-Bend Achromat (QBA)[1]. A QBA cell contains two DBA cells with modification in dipole length but keep the circumference the same with 486m. The QBA lattice can be treated as a compromised design between the DB nonachromat and achromat lattice. The QBA lattice proves a small emittance and some zero-dispersion straight sections.

Both lattices serve small emittance for high brightness and therefore make scatterings become a dominate term for beam lifetime issue. Meanwhile the small emittance needs strong sextupoles for correcting the large chromaticities generated by strong focusing that inevitably leads to significantly nonlinear beam dynamics. This paper presents the lifetime estimation in the present of nonlinear calculation of the energy acceptance. Table 1 gives the relative parameters for different lattices we used in the calculation.

Table 1: Lattice parameters

	Emittance [nm-rad]	1st /2nd order momentum compaction factor	Bunch length [ps]	RF acceptance [%]
DB nonachromat	1.7	2.464×10^{-4} / 2.453×10^{-3}	9.25	4.91
DBA	5.2	3.136×10^{-4} / 1.972×10^{-3}	10.44	4.35
QBA	3.0	2.712×10^{-4} / 2.107×10^{-3}	9.11	4.81

The peak RF voltage is 3.5MV in TPS design which gives a RF acceptance about ±5% determined with 1st order momentum compaction factor only. And the half height of the chamber is 5 mm.

TOUSCHEK TRACKING

Touschek Lifetime Formula

Touschek scattering describes a large-angle Coulomb collision between two electrons inside a bunch with transverse momentum transferring into longitudinal plane. The change in the longitudinal momentum can lead to particle loss if the momentum exceeds the momentum acceptance of the ring.

The Touschek half lifetime for non-relativistic transverse velocities is given by[2]

$$\frac{1}{\tau_{1/2}} = \frac{\sqrt{\pi} r_e^2 c N_b}{\gamma^2} \left\langle \frac{D(\zeta)}{V\delta_{acc}^2} \right\rangle_{ring} \quad (1)$$

with N_b is the number of electrons in a bunch, $V = 8\pi^{3/2}\sigma_x\sigma_y\sigma_s$ the bunch volume, δ_{acc} is the local relative energy acceptance, $\sigma_{x'} = \frac{\varepsilon_x}{\sigma(x)}\sqrt{1+\frac{H\sigma_\delta^2}{\varepsilon_x}}$ is the normalized transverse momentum with $H = \gamma_x D_x^2 + 2\alpha_x D_x D_x^{'} + \beta_x D_x^{'}$, $D(\zeta)$ is a special function

$$D(\zeta) = \sqrt{\zeta}\left\{-\frac{3}{2}e^{-\zeta} + \frac{\zeta}{2}\int_\zeta^\infty \frac{\ln u}{u} e^{-u} du + \frac{1}{2}(3\zeta - \zeta\ln\zeta + 2)\int_\zeta^\infty \frac{e^{-u}}{u} du\right\}$$

with $\zeta = \left(\frac{\delta_{acc}}{\gamma\sigma_{x'}}\right)^2$. The plot of $D(\zeta)$ is given in fig 1.

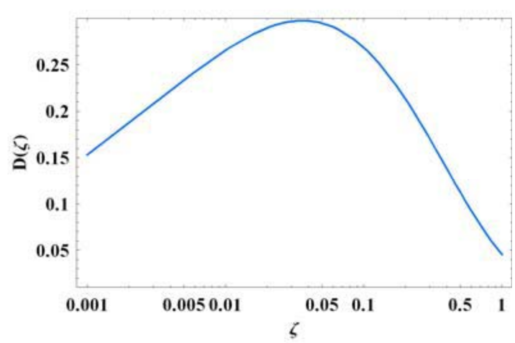

Figure1: plot of $D(\zeta)$

Energy Acceptance Estimation

In views of particles undergoing scattering with momentum change δ, we have to calculate momentum acceptance to judge if particle loss or not. This momentum acceptance could be determined by the lattice acceptance or RF acceptance.

For modern light sources, the linear calculation of momentum acceptance is insufficient. Considering of calculating the lattice energy acceptance, people have to include nonlinear variation of twiss parameters, α,β,γ with momentum δ and high order dispersion of closed orbit with momentum δ. Then the off energy dynamic acceptance searched in one location is propagated along the ring using the off momentum beta functions.

Besides, a small first order momentum compaction factor comes up consequently for obtaining low emittance. The second order compaction factor becomes significant and should be included in the longitudinal motion. As a result the synchrotron motion is nonlinear and RF bucket becomes asymmetric which could reduce the RF energy acceptance.

These nonlinear effects mentioned above have been included in BETA code earlier[3,4]. Thus we choose BETA[5] code to do the energy acceptance estimation.

RESULTS

Touschek Lifetime for Different Lattices

We can foresee the Touschek lifetime by examining equation (1). The loss rate $1/\tau$ at a location is proportional to $\frac{D(\zeta)}{V\delta_{acc}^{2}}$. It is noticeable that $D(\zeta)$ function has a maximum equal to 0.3 at ζ is 0.04. Considering the midpoint of long straight section and the same energy acceptances, say 4.5%, the ζ values for our lattices lies between 0.1 and 0.4. The $D(\zeta)$ for DB nonachromat is 0.1425 which is smaller than 0.2573 for DB achromat. However, the DB achromat has a larger emittance than nonachromat one by three times. The larger emittance gives plenty contribution to bunch volume therefore the Touschek lifetime for DB achromatic is longer.

QBA has a compatible emittance in comparison with DB nonachromat lattice, however the $D(\zeta)$ is slightly lower than DBA one therefore get a tiny gain in lifetime. Fig 2 and fig 3 show the energy acceptance and Touschek lifetime calculations for DBA and QBA lattices.

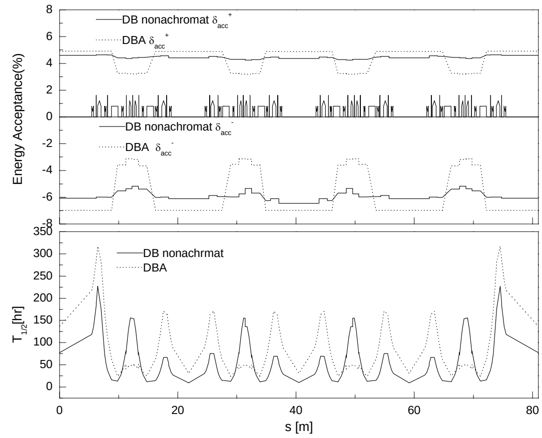

Figure 2: Energy acceptance and Touschek lifetime results along a super-period for DB in achromat and nonachromat mode.

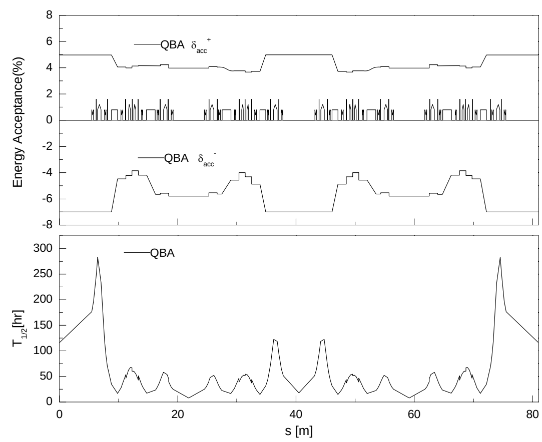

Figure 3: Energy acceptance and Touschek lifetime results along a super-period for QBA.

Touschek Lifetime and RF Voltage

Touschek lifetime strongly depends on the available energy acceptance. The energy acceptance is fully determined by RF when the RF voltage is low. Nevertheless, with increasing RF voltage the lattice acceptance gradually plays a major role than RF acceptance. Therefore raising the RF voltage to increase Touschek lifetimes is not an effective solution.

Fig 4 displays the Touschek lifetime as a function of RF voltage obtained from BETA code.

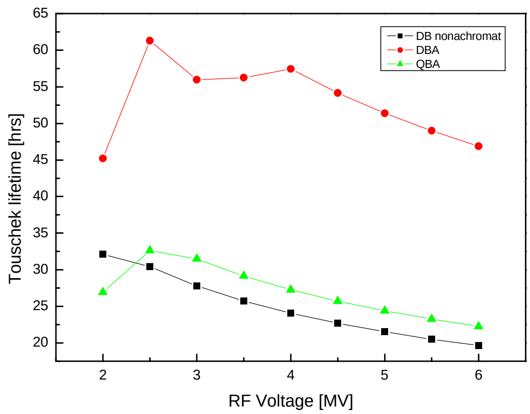

Figure 4: Touschek lifetime as a function of RF voltage.

For TPS achromat lattice, both DBA and QBA, beyond 2.5MV the acceptance is taken over by lattice acceptance. Further increasing the RF voltage to enlarge RF acceptance does not gain lifetime but decrease the lifetime because of the shortened bunch length.

Gas Scattering Lifetime

Scatterings between electron and residual gas molecules also bring a significant contribution to lifetime reduction. The gas scattering lifetime is limited by gas pressure, transverse acceptance, and energy acceptance. Assuming residual gas molecule equivalent to nitrogen, the gas scattering lifetime is calculated by ZAP [6]. Both elastic and inelastic gas scattering are considered. The gas scattering lifetime as a function of equivalent pressure of N_2 is shown in Fig 5.

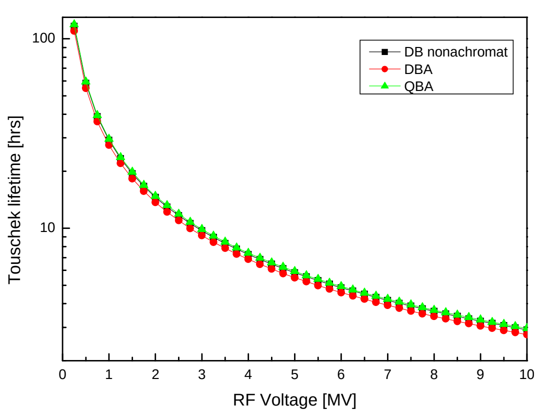

Figure 5: Gas scattering lifetime as a function of nitrogen equivalent gas pressure.

From the above calculation data, we can estimate the total lifetime for individual lattices. One should be careful that gas lifetime is defined as decay to 1/e in ZAP. Table 2 gives a summary for lifetime. It displays that the gas lifetime might become dominated for TPS lattice.

Table2: Lifetime summary

Lattice	Touschek [hrs]		Gas(1/e) [hrs]	Total(1/e) [hrs]
	(1/2)	(1/e)		
DB nonachromat	25.8	37.22	29.1	16.33
DBA	55.7	80.36	27.4	20.43
QBA	29.1	41.98	29.6	17.36

CONLUSION

We have lifetime estimation for the TPS 3GeV electron storage ring with nonlinear energy acceptance using BETA tracking code and gas lifetime calculation using ZAP. The Touschek lifetime could be further improved by optimizing the sextupole scheme. Lengthening the bunch length by operation at lower RF voltage or introducing harmonic RF cavities will help to gain Toushek lifetime. Since different codes are used, more examination about lifetime issue needs further work.

REFERENCE

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