Study of Energy Ramping Process Applied to the LNLS Synchrotron Light Source (Brazil)

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Abstract

Acceleration cycle studies of the LNLS 1.15 GeV UVX electron storage ring are described. Since this ring will initially be injected at low energies (100 MeV), questions related to the behavior of beam lifetime during the ramping period (about 10 s), especially at the lowest energies, are crucial for the successful operation of the machine. In this work, we present results of Touschek lifetimes, due to single and multiple scattering effects, compared with damping times at various energies. We show that these effects should not lead to appreciable stored current losses.

I. INTRODUCTION

The LNLS 1.15 GeV UVX[1] electron storage ring will be injected using a beam from a linear accelerator. The electrons will be accumulated at low energy - 100 MeV. Ramping to the nominal energy - 1.15 GeV - will follow and the final current will be 100 mA. Two injection schemes will be used: conventional injection (linac pulses at a rate determined by the stored beam oscillation damping time) and injection with anomalous repetition rate (linac pulses at a much faster rate and the stored beam not be damped). Although some other electron synchrotrons are using injection at low energy[2], there is still an appreciable stored current loss during the ramping process.

The ramping period, in our case, is about 10 seconds and during this time, especially at the lowest energies, some coherent and incoherent collective effects could influence the equilibrium beam dimensions, the lifetime and the accumulated current. Initially Touschek scattering, intrabeam scattering (IBS), beam-gas interactions and damping time have been studied. No microwave instability has been considered. All calculations shown here have been done using local computer codes.

II. RAMPING CONDITIONS

Although the energy and the RF voltage are changed during the acceleration cycle, there is an adiabatic change of the parameters of the ring (η_0, Ω_0, ϕ_0, p_0, R_0 and $\hat{V}$). The condition[3]:

$$\varepsilon = \frac{1}{\Omega_s^2}\frac{d\Omega_s}{dt} << 1 \qquad (1)$$

from the Boltzman-Ehrenfest adiabatic theorem is still valid for the LNLS UVX ring parameters.

The dipole magnetic field will increase as a sin-function and the RF voltage as two straight lines with different inclinations. The increases are shown in figure 1.

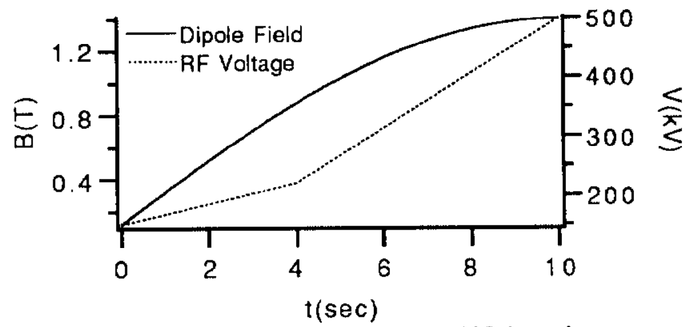

Figure 1- Dipole Magnetic Field and RF Voltage increase during the accelerating cycle.

III. LIFETIME

A. Beam-gas interactions

The interaction of the electron beam with the molecules of residual gas (beam-gas scattering) includes four processes: the elastic scattering of the stored beam on nuclei (in transverse planes x and y, i.e., $1/\tau_{scat}=1/\tau_{scat-x}+1/\tau_{scat-y}$), the bremsstrahlung on nuclei and the elastic and the inelastic scattering on electrons. All these effects lead to particle losses and reduce the beam lifetime.

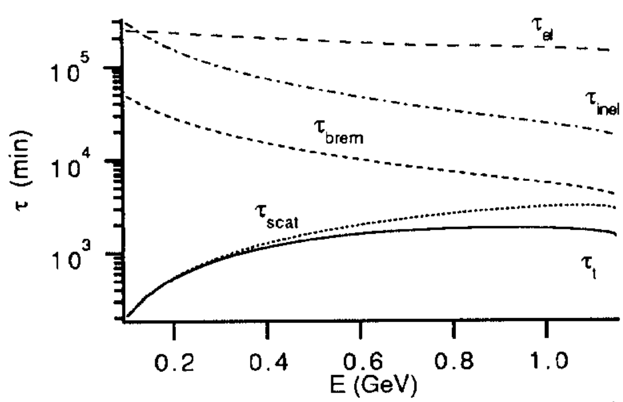

Figure 2 - Lifetime due to beam-gas interactions. τ_{scat} is due to the elastic scattering on nuclei, τ_{brem} is due to the bremsstrahlung on nuclei, τ_{el} is due to the elastic scattering on electrons, τ_{inel} is due to the inelastic scattering on electrons and τ_t is the total lifetime for the four processes.

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The computation has been carried out using the formulae from references [4] and [5]. For our ring, the residual gases, at the pressure of 0.3 nTorr at 100 MeV and 3.0 nTorr at 1.15 GeV, are: H (90%), CO (4%), CO_2 (4%) and CH_4 (2%) and the current used was I = 100 mA. The results show that the worst-case contribution for the lifetime comes from the elastic scattering on nuclei in the vertical plane, but the full lifetime, resulting from different types of beam-gas interaction, is larger than 3:30 hours at 100 MeV. The results are displayed in figure 2.

B. Intrabeam Scattering

Intrabeam scattering (IBS) is a multiple Coulomb scattering of charged particles in a bunched beam. It induces an increase of bunch dimension and, therefore, a reduction of the beam lifetime due to the collisions of the particles in the vacuum chamber. IBS is in essence a diffusion process in all dimensions.

IBS dominates the emittance during injection energy up to about 500 MeV, for the LNLS UVX ring. Transverse oscillation energy will be transferred into the longitudinal direction through Coulomb scattering among electrons. So, bunch lengthening and emittance growth (transverse and longitudinal) will occur.

The calculations were done using the formulation given by J. Le Duff in reference [6]. Initially, we found the values of σ_E/E and then σ_x and σ_y, where:

$$\sigma_x = [\beta_x U_x + D^2]^{1/2} \frac{\sigma_E}{E}$$
$$\sigma_y = [K \beta_y U_x]^{1/2} \frac{\sigma_E}{E} \tag{2}$$

with

$$U_x = \frac{J_E}{J_x} < \frac{1}{\beta_x}[D^2 + (\beta_x D' - \frac{1}{2}\beta_x' D)^2] > \tag{3}$$

where K is the coupling, J_i is the damping time (see item IV), D is the dispersion. The $\beta_{x,y}$ values used in equations (2) are the average.

In figure 3 the longitudinal beam dimension with and without IBS is shown and in figure 4 the emittance, also with and without IBS. All calculations for IBS were carried out with bunch current of 1 mA and 10% coupling.

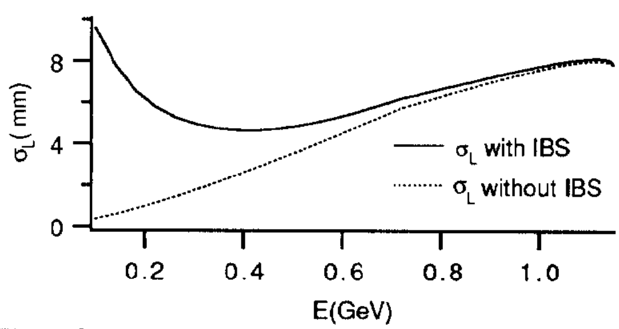

Figure 3 - Longitudinal bunch length during the acceleration cycle with and without IBS. I_{bunch}=1 mA and coupling=10%.

C. Touschek Effect

The Touschek Effect is also caused by Coulomb scattering, but is given by large single scattering events for which only the energy transfer from transverse to longitudinal direction is examined.

As in IBS's computation, we used I_{bunch} = 1 mA and 10% of coupling. The bunch dimensions and the energy acceptance used were obtained from IBS calculations. Because the Touschek lifetime depends on the machine parameters, we computed the average values for the optical functions.

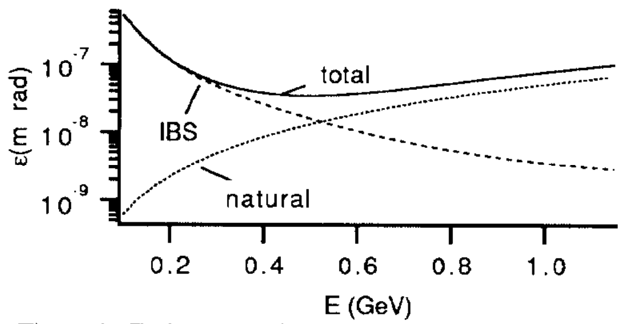

Figure 4 - Emittance during the acceleration cycle with and without IBS. I_{bunch} = 1 mA and coupling = 10%.

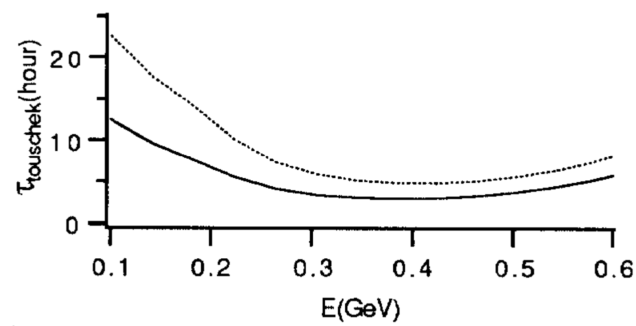

Figure 5 - Touschek lifetime during part of the acceleration cycle (E ≤ 600 MeV), calculated using the emittance total (see figure 4). The dashed line corresponds to the calculation with relativistic approximation and the solid line without relativistic approximation.

There are many formulae to estimate the Touschek lifetime with different approximations[7]. In our study, we used two: one given by J. Le Duff[4] and another, where there is no relativistic approximation, given by U. Völkel[8]. The result is shown in figure 5 only up to 600 MeV. After this energy, the Touschek lifetime increases exponentially up to more than 150 hours. Although there is a small difference between the two calculations, the shortest lifetime is around 3 hours for E ≈ 380 MeV.

D. Total Lifetime

The overall beam decay rate is given by:

$$\frac{1}{\tau} = \frac{1}{\tau_{gas-scat}} + \frac{1}{\tau_{Touschek}} + \frac{1}{\tau_{quantum}} + \ldots \tag{4}$$

In our case we have not included the quantum lifetime, even though the photon emission process alters the electron momentum. The beam-gas interaction, the Touschek scattering and the IBS are dominating.

Although no microwave instability has been considered until now, we can see one significant reduction of beam lifetime at the energy between 350 and 400 MeV. Up to 800 MeV the Touschek lifetime (including the IBS) is dominating. The shortest lifetime is 2:30 hours at 385 MeV. See figure 6.

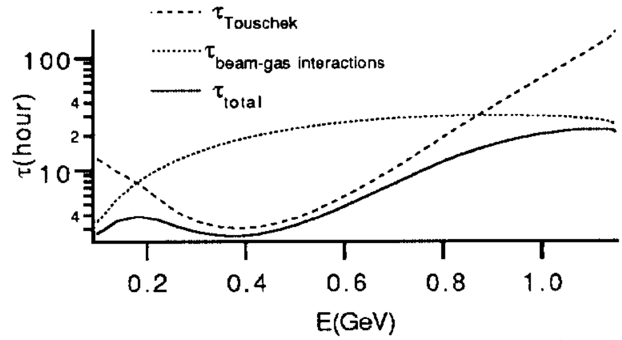

Figure 6 - Total lifetime, during the acceleration cycle, including beam-gas interaction, intrabeam scattering and Touschek effect without relativistic approximation. No microwave instability has been considered. I_{bunch} = 1 mA and coupling = 10%.

IV. DAMPING TIME

The damping times of the transversal oscillations or synchrotron oscillations are given by[5]:

$$\tau_i[\mathrm{ms}] = \frac{C[\mathrm{m}]\rho[\mathrm{m}]}{13.2 J_i E^3[\mathrm{GeV}]} \qquad (5)$$

where i = x or y (betatron oscillations) or ε (synchrotron oscillation), with $J_x = 1 - D$ and $J_\varepsilon = 2 + D$, where $J_x + J_y + J_\varepsilon = 4$ and $D = I_4/I_2$ (see ref. [5]).

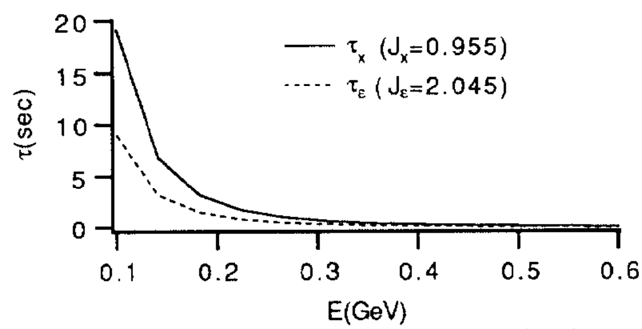

Figure 7 - Damping time during part of the acceleration cycle ($E \leq 600$ MeV). τ_x is the solid line and τ_ε is the dash line.

For the LNLS UVX ring, the damping time of the horizontal and synchrotron oscillations are displayed in figure 7. The time for one revolution is 300 nsec and the ramping time is 10 sec, but, on the other hand, τ_ε is ≥ 0.1 sec for $100 \leq E \leq 190$ MeV and τ_x is less than 0.1 sec for $100 \leq E \leq 575$ MeV. If we decrease the damping time of the betatron oscillations (and, consequently, increase the damping time of the synchrotron oscillations), we will still have no damping in either oscillation during part of the acceleration cycle ($E \leq 600$ MeV).

V. CONCLUSIONS

Beam-gas interactions, Touschek single and multiple scattering and damping time have been investigated during the acceleration cycle for the LNLS UVX ring. Although no microwave instability and ion trapping have been included, the result (figure 6) shows that there is a decrease of lifetime at about 400 MeV.

We also have shown that there is no damping of horizontal or synchrotron oscillations up to about 600 MeV. It is not possible to modify these damping times during the acceleration cycle to values on the order of 0.1 sec or less.

Tracking of particles during part of ramping time has also been done, up to 600 MeV using the code TeaPot[9]. The calculation was performed with 230 particles and 1000 turns in the lattice with sextupoles and systematic multipole errors included. The ramping time (3.5 sec for E_f = 610 MeV) was divided into 14 periods of 0.25 seconds each. Tracking has been done successively for each period using as input the output from previous one. The energy and RF voltage for each period correspond to the values displayed in figure 1. Although we supposed that the energy increased, we used the last beam dimensions because there is no damping. The evolution of the beam shows that there is a reduction of the energy dispersion. No loss has occurred, but each particle was tracked alone, i.e., no collective effect was included.

The future study should contain microwave instability and a tracking computation where all the collective effects (coherent and incoherent) are incorporated.

VI. REFERENCES

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