Section 6 VLER Beam Dynamics

INTRABEAM SCATTERING

In an electron storage ring, the multiple Coulomb scattering of the charged electrons within a bunch leads to the growth of emittance in all three dimensions. The growth rates are proportional to the fourth power of the inverse of beam energy (for example, see Ref. 7). Hence, at the lower end of the energy range (150MeV), this effect could become the dominant factor in determining the equilibrium beam size.

To estimate the effect of the intrabeam scattering, we compute the growth rates of emittance in all three dimensions as a function of energy using MAD [8] (formulated by Bjorken and Mtingwa [9]). The latest “low” emittance design lattice is used in the calculation, as it is the more problematic case for this effect. At all energies, the bunch length is fixed at 1. cm, the horizontal emittance is kept at the constant value of 260 nm, and the vertical emittance is assumed as 10% of the horizontal one. The values of the charge per bunch at different energies are interpolated based on the table of the main parameters in the first section. The results of the calculation are plotted in Figure 6-1 and Figure 6-2. They show that the growth rate is small compared to the damping rate due to the synchrotron radiation when the energy is larger than 200 MeV, and it increases rapidly once the energy drops below 200 MeV. This result indicates that the energy of the beam has to be larger than 200 MeV to maintain a reasonable beam size and beam lifetime since there is no equilibrium distribution if the growth rate is larger the damping rate. However in this estimate the larger beta excursions that the 150 MeV lattice presents, that can help in decreasing the growth rate, were not taken into account. Otherwise, to lower the energy below 200 MeV, we may need to make bending magnets stronger or make the ring smaller.

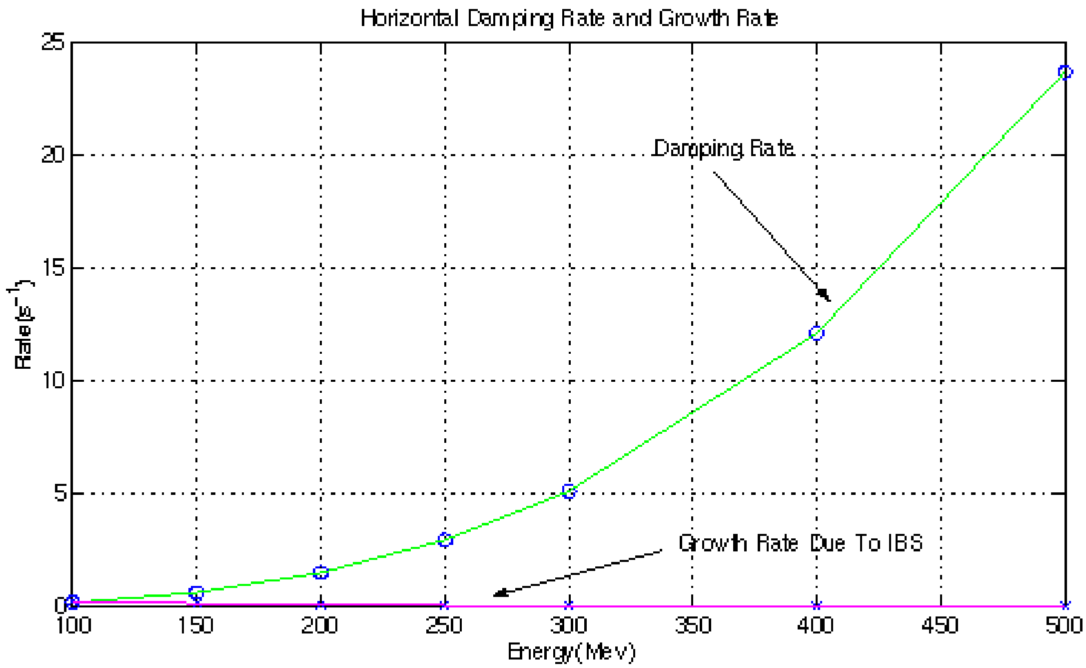

Fig. 6-1: IBS horizontal growth rate as a function of Energy (Low ε_x).

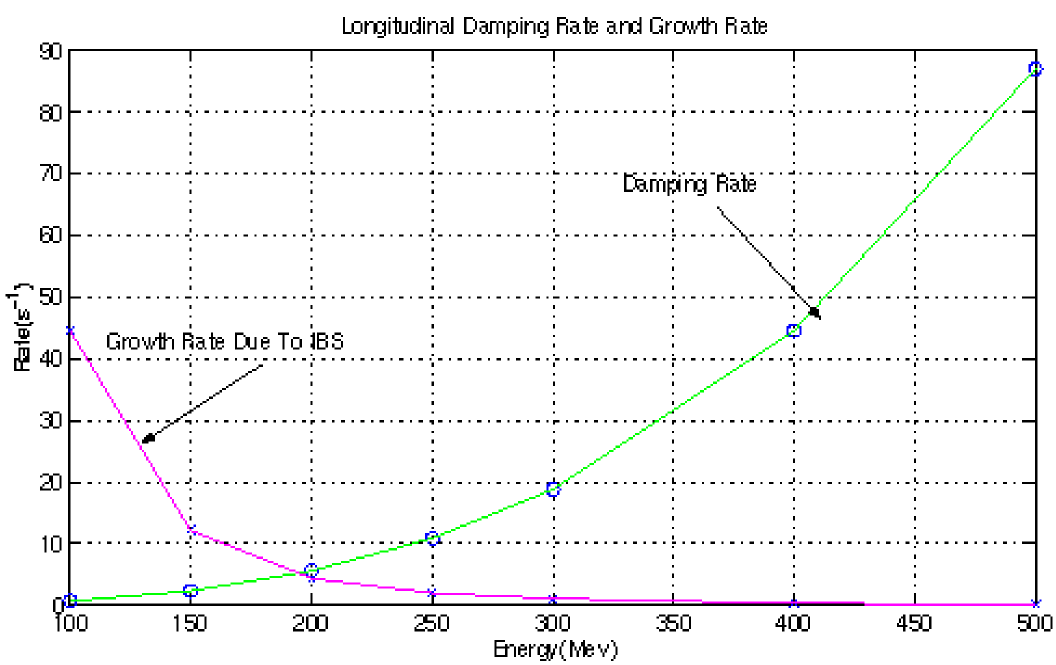

Fig. 6-2: IBS longitudinal growth rate as a function of Energy (Low ε_x).

TOUSCHEK EFFECT

The lifetime of the electron beam due to the Touschek effect is estimated as a function of energy using the simple formula by Le Duff [10] for flat beams. At all energies, the momentum acceptance is calculated with a fixed RF voltage of 100 kV. Two cases are reported, the “low” and “high” emittances considered in Sec. 5, with their values fixed at all energies. The result of calculation is shown in Figures 6-3 and 6-4, as a function of the number of particles per bunch. Each curve refers to an energy value, ranging from 100 MeV (the lowest) up to 500 MeV in 50 MeV steps. Given the charge per bunch tabulated in the list of main parameters, the shortest beam lifetime is larger than 10 hours when the beam energy is 150 MeV for the low emittance lattice.

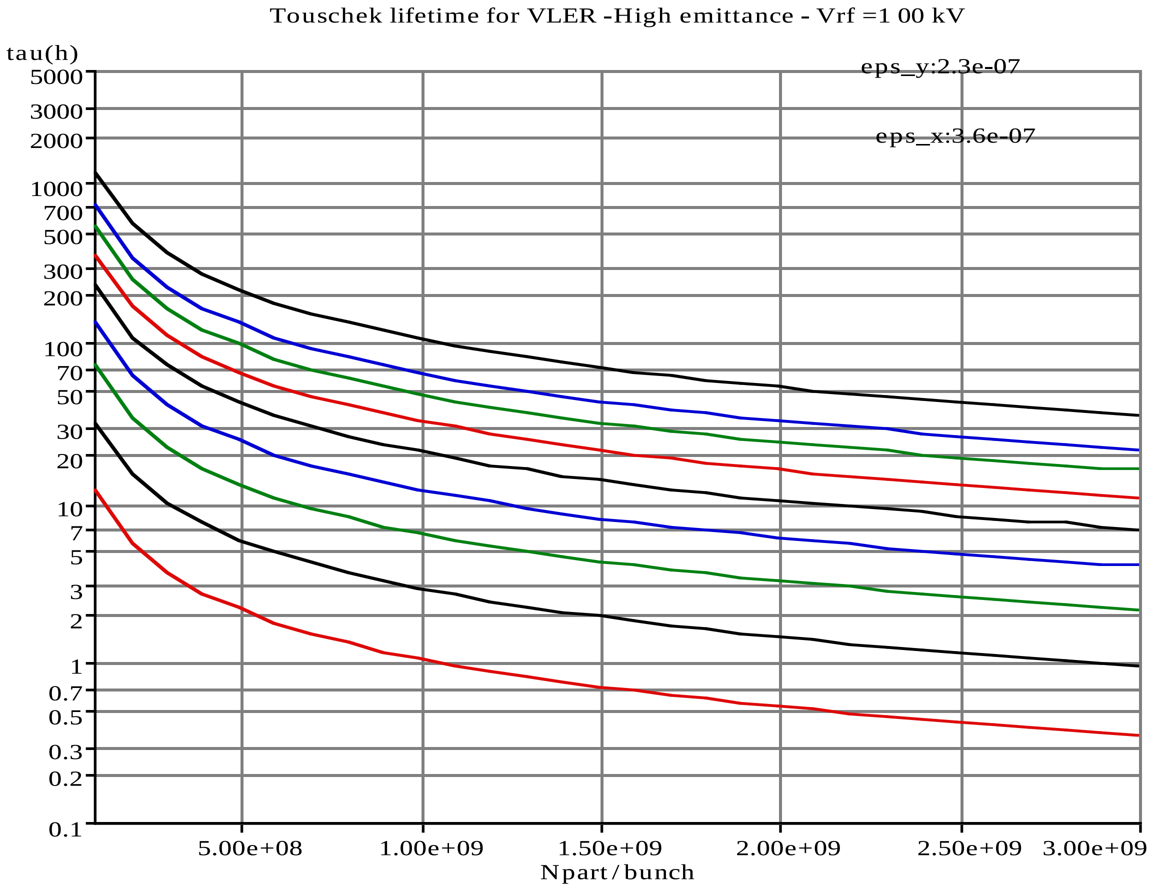

Fig. 6-3: Touschek lifetime as a function of N. particles/bunch (High ε_x). Each curve is a different energy, from 100 MeV (lower) to 500 MeV (upper).

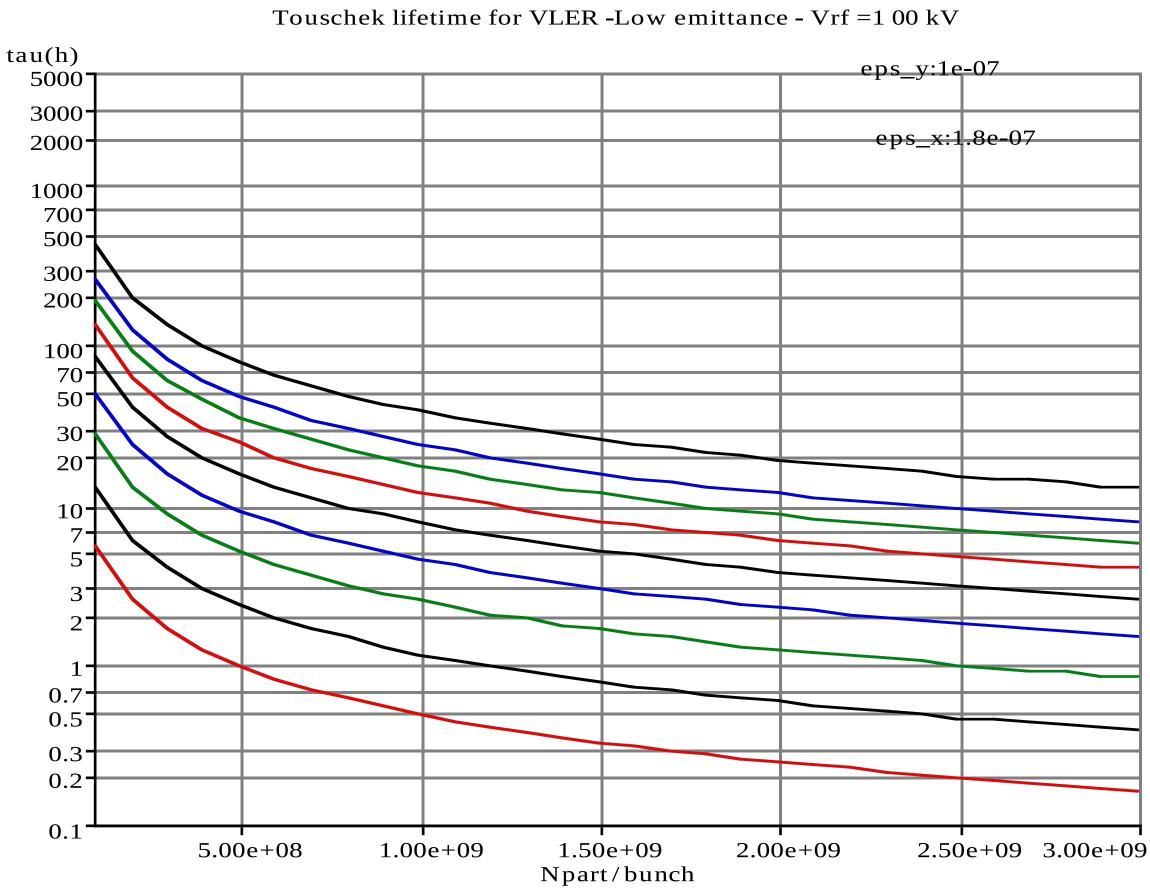

Fig. 6- 4: Touschek lifetime as a function of N. particles/bunch (Low ε_x). Each curve is a different energy, from 100 MeV (lower) to 500 MeV (upper).

COLLECTIVE EFFECTS

Consideration of collective effects may benefit from comparison to PEP-II and SLC DR. The comparison is not straightforward for the SLC DR, for example, as it has comparable size and energy, but higher bunch current, faster damping and fewer bunches.

Without an precise vacuum design we can only estimate the machine impedance. From analogy with the SLC DR, we can expect a machine inductance of about 40 nH. The main contribution to the narrow-band (NB) part of the real part of impedances is given by the RF cavity, while the broad-band (BB) is dominated by the resistive wall (RW) impedance. The 35 m long aluminum beam pipe with resistivity ρ = 16 nm-Ohm gives Z_T = 1.9 kOhm/m at the first revolution harmonic.

The transverse coupled bunch instability driven by the RW has growth rate:

$$\frac{1}{\tau} = \frac{I_{beam} f_{rev} \beta_{\perp}}{E/e} \mathrm{Re} Z_{\perp}$$

or τ = 7.8 ms (I_{beam} = 80 mA, E = 500 MeV, β_T = 50 m) for fractional part of the tune not too close to an integer. This has to be compared to the damping time τ_d = 43 ms. A strong transverse feedback is needed to suppress this instability. The quadrupole CB transverse instability is usually $(\sigma_T/b)^2$ slower and should not be a problem. The damped RF cavity has still few NB modes with a shunt impedance $R_T \approx$ 350 kOhm/m at f ≈ 1.5 GHz. They are stronger than the RW, but can be suppressed by a dedicated feedback.

The growth rate of CB longitudinal instability is dominated by the NB HOM cavity modes:

$$\frac{1}{\tau} = \frac{I_{beam} \alpha_c \omega_{HOM}}{4\pi Q_s E/e} \left(\frac{R}{Q} \right) Q_L$$

For the PEP-II cavity, the most dangerous mode has $(R/Q)Q_L$ = 6 kOhms at f_{HOM} = 1.3 Ghz. Then τ = 0.3 ms (momentum compaction α_c = 0.066, energy spread δ = 3.51^{-4}, and rms bunch length σ_l = 1 cm correspond to the synchrotron tune Q_s = 0.013). The growth time requires strong longitudinal feedback comparable with that of PEP-II.

Single bunch effects are less damaging. The SLC damping ring has problems with the saw-tooth instability at the bunch current only about 2.5 mA. This is much higher than in VLER but still need to be checked because of the low damping time. The usual criterion for the microwave instability limits the effective impedance $(Z/n)_{eff}$ < 6 Ohms. This is much larger than in PEP-II where there are no microwave problems and damping time is comparable with the VLER one. The transverse microwave instability and the mode coupling instabilities should not give problems.

Some bunch lengthening should be expected: with an inductance of L = 40 nH, the bunch lengthening is about 30%, but this is beneficial for the IBS and Touschek lifetimes.

The potential well of the beam is shallow, 10-20 times smaller than in PEP-II. Both ion frequencies and ion velocities are lower, scaling as $\sqrt{I_{beam}}$ for comparable beam transverse rms sizes. Ions in the ring have a frequency of about 5 MHz (I_{beam} = 80 mA, σ_T = 0.5 cm), comparable to the revolution frequency. In this case, the beam-ion interaction has distinct resonances when betatron frequency and ion frequency are integer of the revolution frequency. The resonances do not overlap even with frequency spread caused by the betatron modulation in the ring. Hence, there will be no fast ion instability, and resonances can be detuned. The 5% gap used in PEP-II here will not clear ions, but still reduces the ion density. A careful choice of tunes should eliminate ion effects.

Because the gaps in both rings cannot be made equal, some additional adverse beam-beam PACMAN type effects may be induced in the trains and have to be studied.