2.7 Current and Lifetime

Our estimates so far indicate no major obstacles in the way of achieving the design current of 400 mA in multibunch operation mode. Single bunch currents in excess of 10 mA seem to be feasible.

2.7.1 Multibunch instabilities

Coupled bunch instabilities, caused mainly by the high Q resonances in the RF cavities, will limit the total current in the machine.

We have chosen the single cell cavities of ELETTRA type for the SLS RF system. With this type of cavities it is possible to control the coupled bunch instabilities by properly tuning the frequency of the higher order modes. This method, which was successfully demonstrated at ELETTRA should be able to provide sufficient control of these instabilities in the SLS case (cf. details in the ring RF system Section 2.5).

2.7.2 Single bunch collective effects

Electron beam interaction with the surroundings causes the beam parameters such as bunch length and energy spread to depend on current.

Impedance

This interaction can be modeled by describing the beam environment (vacuum chamber, RF cavities, etc.) in terms of impedance. Broad band resonator impedance provides a useful model for the estimates of the main effects.

Careful design of the vacuum system components should result in a very low value of the equivalent broad band impedance with resonant frequency near the vacuum chamber cut-off frequency, as has been recently demonstrated at ALS, ELETTRA, ESRF and LEP. The effective impedance seen by a *short bunch* would then be further reduced. However, observations indicate also very high resonant frequency impedance (from such sources as bellows, etc.) with low, but non-negligible effective impedance. Simplified model contained in the ZAP code [1] was used for the present estimates of the single bunch collective effects. The model parameters were adjusted to obtain bunch lengthening results roughly corresponding to those observed at ALS and ELETTRA. This corresponds to the longitudinal impedance (in the low frequency limit) of 1 Ohm.

Bunch lengthening estimates

Two regimes are distinguishable: *potential well* and *turbulent* bunch lengthening. In the turbulent regime both the bunch length and the energy spread increase with current, starting from some threshold current value. Below the threshold, in the pure potential well regime, the bunch length increases or decreases with current, depending on the character of the overall impedance that the beam sees.

The results of the bunch lengthening and energy spread widening as a function of single bunch current are shown in Figure f27_a. They were used further in estimates of the effects of the intrabeam scattering on the equilibrium emittance and on the Touschek lifetime.

Transverse mode coupling instability

Careful control of the transverse impedance of the vacuum chamber should insure that the transverse mode coupling instability threshold will be well above the design single bunch current. For the model used, corresponding to the transverse impedance of 100 kOhm/m at an average value of the betatron function of 7 m, the single bunch current threshold would be at 60 mA.

2.7.3 Beam lifetime

The main processes contributing to the loss of particles from the beam include scattering on the residual gas and intrabeam scattering. These effects also change the equilibrium beam distribution away from Gaussian one, namely by populating the tails of the distribution and hardly affecting the core of the beam.

Touschek effect limited beam lifetime

Small desired emittances result in a very high particle density in the transverse phase space; this leads to a rather short beam lifetime that is dominated by the Touschek effect. As a result of an intrabeam scattering event, the particles' energy may be altered by a large enough amount to be outside the energy acceptance of the machine.

Given the high phase space density of electrons in the SLS design, the conventional value of energy acceptance of 2% would result in Touschek lifetime well below one hour for a single bunch of 10 mA.

Touschek lifetime increases as a cube of the energy acceptance. The effective energy acceptance value varies along the machine (e.g. in the dispersion free sections the vacuum chamber radius of 30 mm would limit the acceptance to 9.6%, whereas the same vacuum chamber in the regions of high dispersion would result in an acceptance that is only half of that value, about 4.8%.). The overall Touschek lifetime (calculated as a weighted average around the machine) was obtained using the code ZAP[1]. Furthermore, in the lifetime calculations the effects of bunch lengthening with current (cf. Figure f27_a), as well as the calculated dynamic acceptance as a function energy deviation (cf. section 2.2 on lattice) have been included.

The results of the lifetime calculations, corresponding to the SLS parameters for the 2.9 nm emittance optics and 1% coupling (cf. the Lattice section) are summarized in Figure†f27_b for the two modes of operation: multibunch (bunch current of 1 mA) and single bunch (10 mA).

With the normal conducting RF system being able to reach 2.6 MV peak voltage (bucket size of ±4.5%) the beam lifetime in single bunch mode can reach 3.5 hours.

Increasing the RF voltage up to 4.2 MV (bucket size of ±6%) by adding a passive super-conducting RF cavity results in a beam lifetime of about 5 hours. As can be seen from Figure f27_b, this RF voltage is close to optimum conditions, since further increase will only result in higher longitudinal density of the bunch and correspondingly shorter Touschek lifetime.

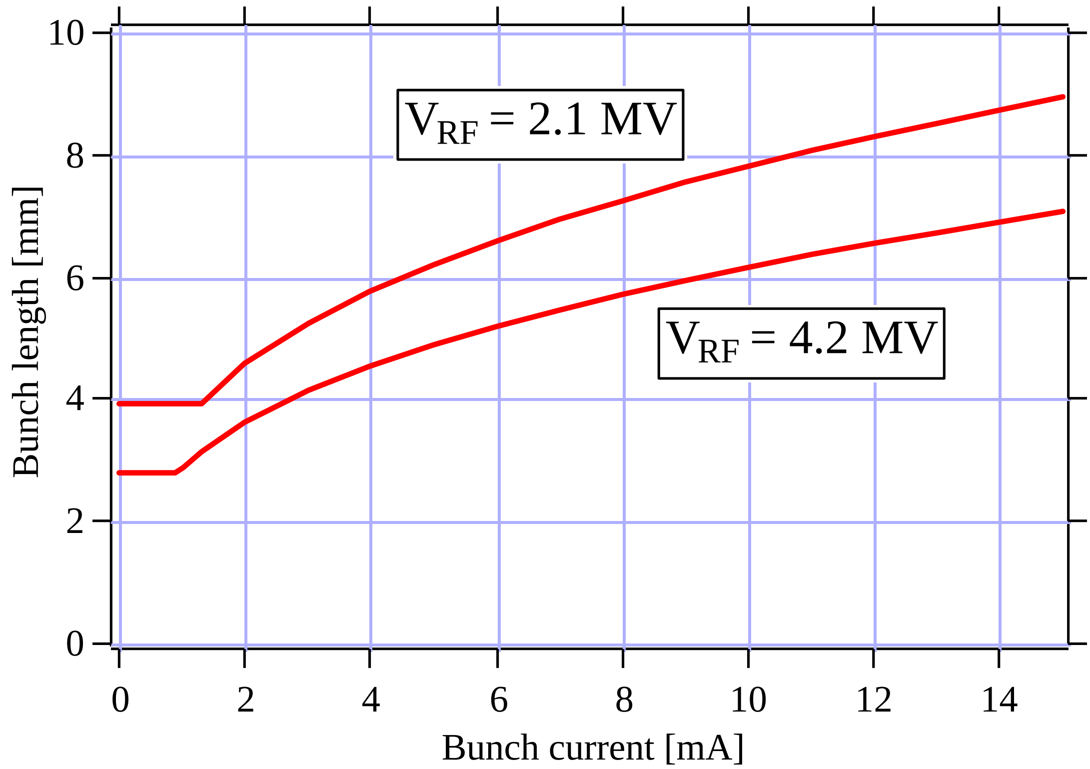
There are other methods of increasing the Touschek lifetime, as, for example, raising the ring energy. The gain would be about 50% in going from 2.1 GeV to 2.4 GeV and would certainly influence overall costs. Similar gain in beam lifetime (albeit at the expense of peak brightness) can be obtained by either compromising on coupling (up to 2.3%) or lowering the single bunch current (down to 7 mA). Higher harmonic RF system could also be used to lengthen the equilibrium bunch length.

Continuous top-up injection is under discussion as an ultimate cure of the lifetime limitations in the storage ring based synchrotron light sources. The present SLS design ameliorates the problem of the Touschek limited lifetime, thus removing the necessity to rely on the continuous top-up injection with its associated open questions (e.g. safety issues).

In the modes that require operation at lower energy (e.g. FEL based on the storage ring) the Touschek limited beam lifetime can become indeed very short. Wide energy acceptance here not only improves the lifetime but also matches well the requirements for high gain FEL operation.

References

[1] M. S. Zisman et al., ZAP user’s guide, LBL-21270, December 1986



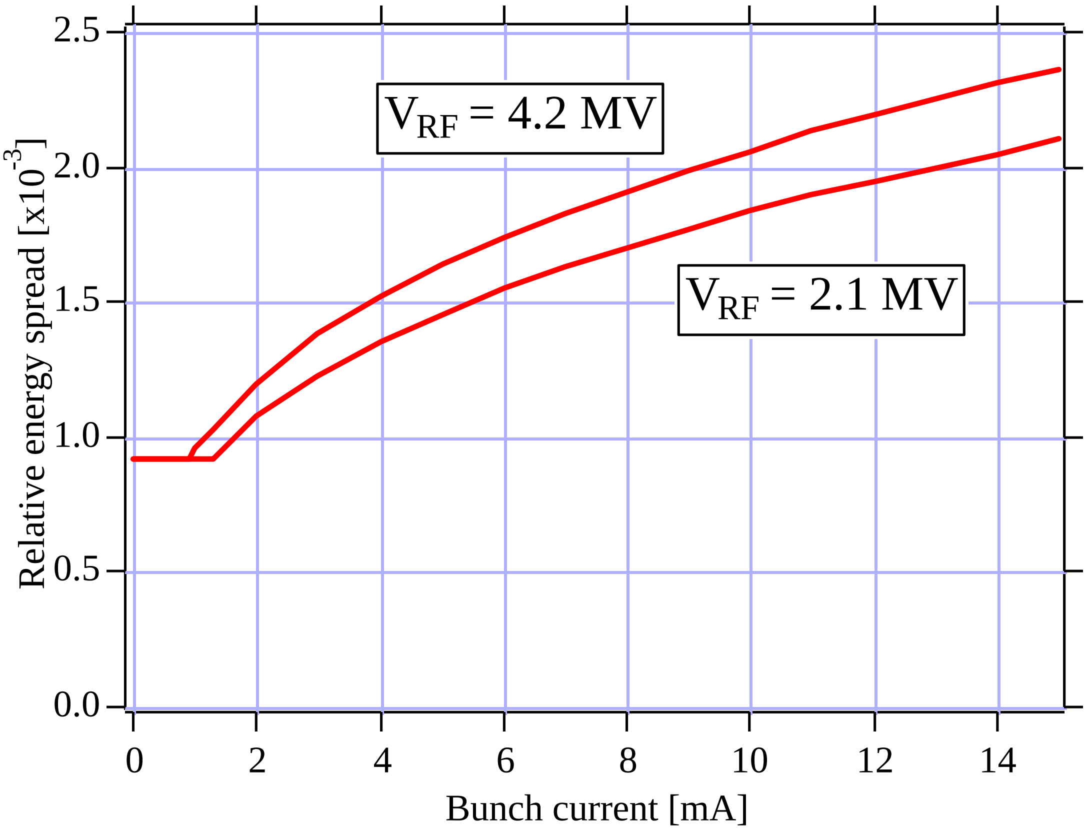


Figure f27_a: Equilibrium rms bunch length and energy spread as a function of single bunch current at the design energy of 2.1 GeV and for two values of the peak RF voltage: 2.1 and 4.2 MV.

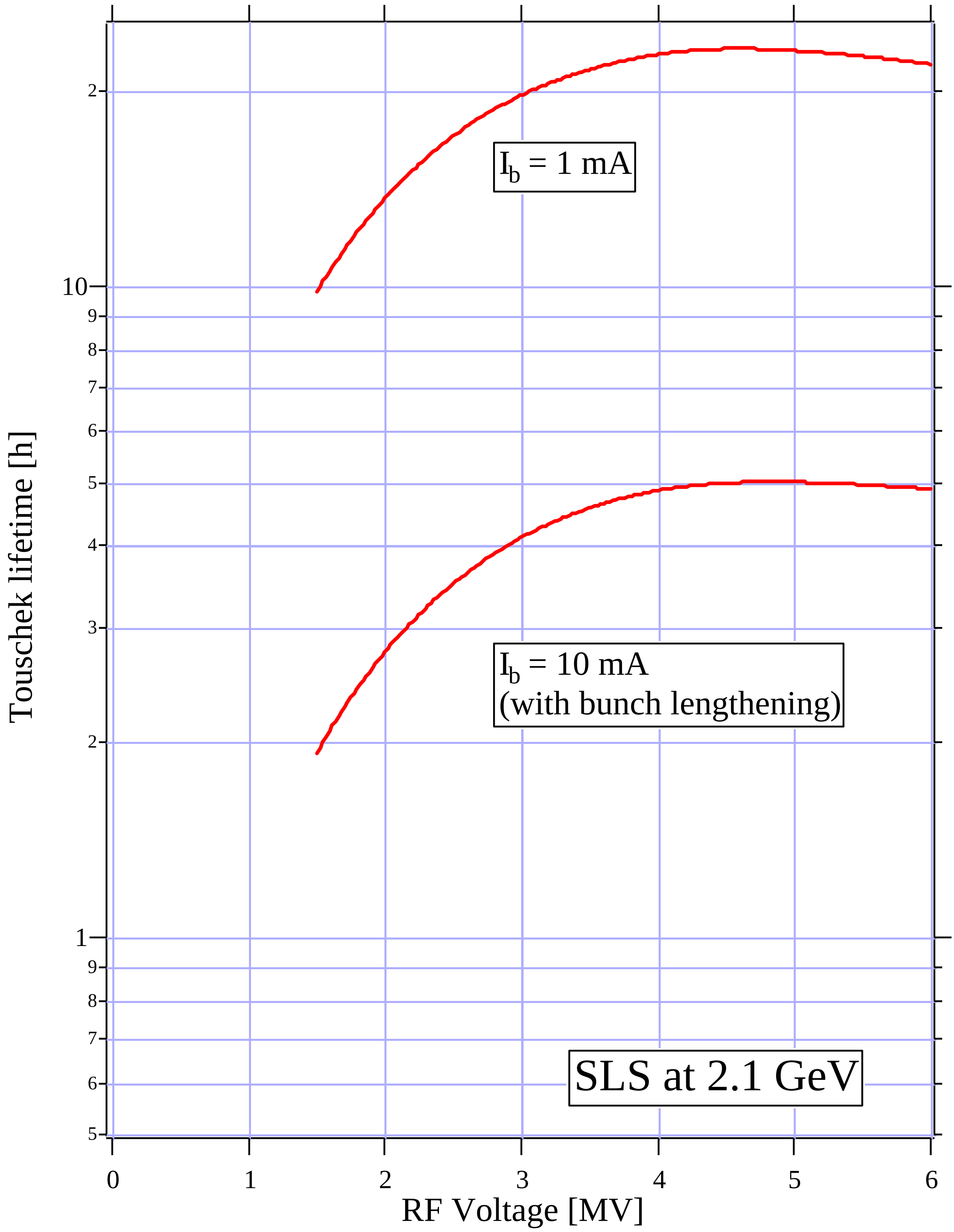


Figure f27_b: Touschek lifetime as a function of the peak RF voltage for two modes of operation: multibunch mode with single bunch current of 1 mA, and single or few bunch mode with single bunch current of 10 mA.