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5 Beam dynamics and layout of the SEE-LS

D. Einfeld and H. Ghasem

5.1 Introduction

The highest priority of a synchrotron light source is that the stored electron beam in the storage ring has to deliver a photon beam with high brilliance and stability. According to the latest technology used for the construction of synchrotron light sources and the required photon spectrum, the following points should be followed for the layout of the SEE-LS.

- The energy should be in the range of 2.5–3 GeV in order to reach, with an 'in-vacuum' undulator, photon energies of 20–30 keV.
- The natural emittance has to be smaller than 250 pmrad; it should be a 4th generation light source.
- The lattice should be optimized for a high photon flux density, which means introducing in a straight section so-called 'mini beta sections'.
- The lifetime should be large enough (greater than 8 hours) to reduce the radiation level in the experimental hall, and there should be only two injections per day.
- The energy acceptance has to be at least 3% (lifetime requirement).
- The design current should be 400 mA.
- A 'topping up' injection mode must be possible so as to have a constant head load on the optical components of the beam lines.
- Feedback systems have to be introduced to achieve sub-micron stability of the stored electron beam.
- According to the available budget, the circumference has to be around 350 m.
- The option to use a single bunch at a later stage should be kept open.
- The pre-accelerator should be a linac with an energy of at least 100 MeV.
- The booster synchrotron should be in the same tunnel as the storage ring. For a high injection efficiency, the emittance of the booster should be smaller than 10 nmrad.
- The booster synchrotron and the storage ring should be in the same tunnel.

5.2 Beam dynamics of the proposed SEE-LS

As discussed in chapter 4, the 3 GeV HMBA lattice will be selected as a solution for the layout of the SEE-LS in order to meet the above-mentioned requirements. To save on investment costs, the machine will first operate with an energy of 2.5 GeV and later be upgraded to 3 GeV. Accordingly, in this section the data of the machine will be presented for the 2.5 GeV case.

The machine functions within one achromat of this solution are presented in Fig. 5.1, and the corresponding magnet structure is shown in Fig. 5.2. The requirements for the circumference C, the emittance ε, and the period N are, with $C = 354$ m, satisfied with $N = 16$ and $\varepsilon = 178$ pmrad. The machine functions (twist parameters) within one achromat are shown in Fig. 5.1 and the magnetic structure in Fig. 5.2. To minimize the number of sextupoles, the phase advance between the middle of the DBA structures should be approximately $\Delta\phi$(horizontal) = 3π and $\Delta\phi$(vertical) = π. In most of the HMBA structures, the bending magnets in the DBA structure have a longitudinal gradient; in this proposal a horizontal gradient will be used in order to decrease the emittance more because of the higher partition number J_x.

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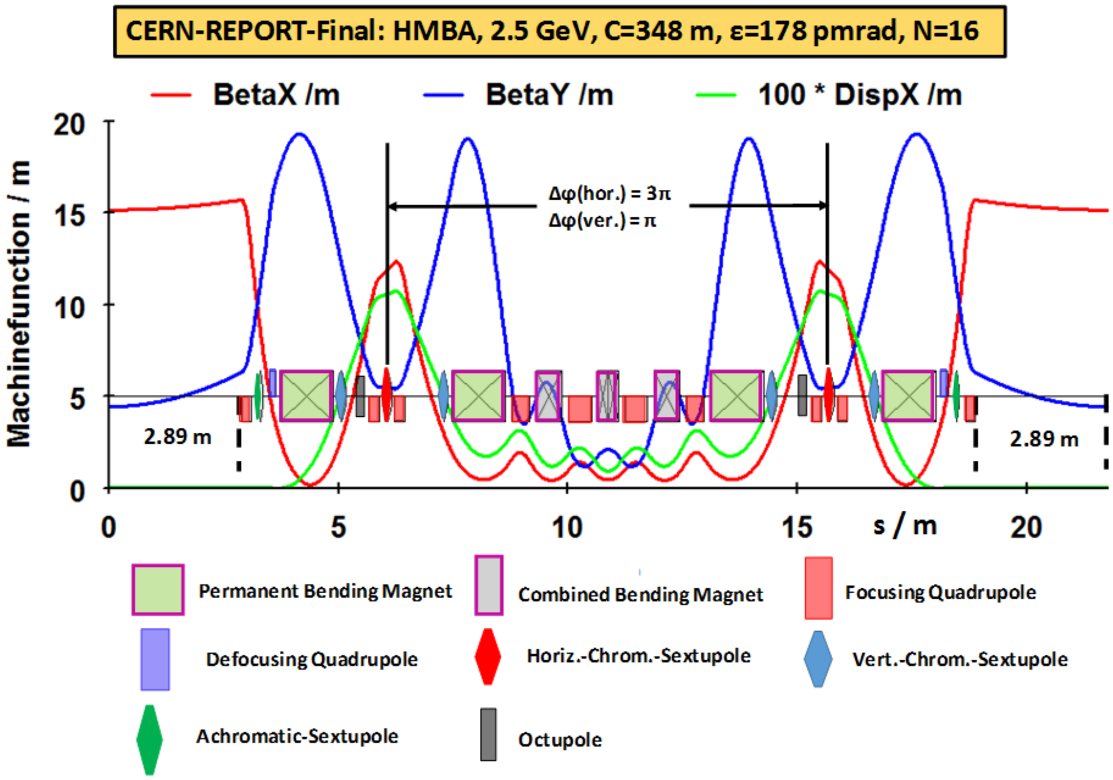


Fig. 5.1: Machine functions within one achromat of the proposed lattice for the SEE-LS

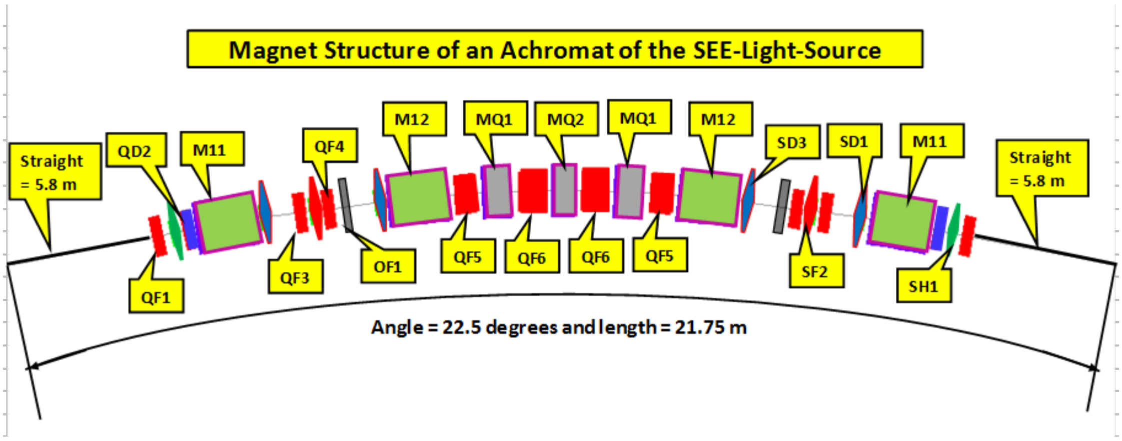


Fig. 5.2: The magnet structure within one achromat of the proposed lattice for the SEE-LS

The functions for the beginning and end of the achromat and DBA structure are displayed in more detail in Fig. 5.3, and those for the matching between the two DBA structures are shown in Fig. 5.4. The cross-sections of the beam in the middle of the straight sections are $\sigma(x)$ = 51.2 μm and $\sigma(y)$ = 4.7 μm for a coupling of 3%, leading to a vertical emittance of 5 pmrad, which is the lowest emittance that has been reached so far. The resonance diagram with the working point and the movement of the tunes with energy are given in Figs. 5.5 and 5.6, respectively.

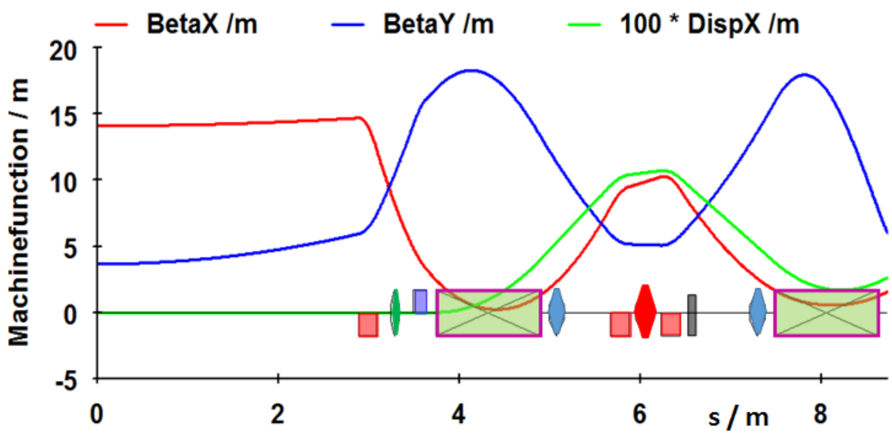


Fig. 5.3: The machine functions within the matching section of the SEE-LS

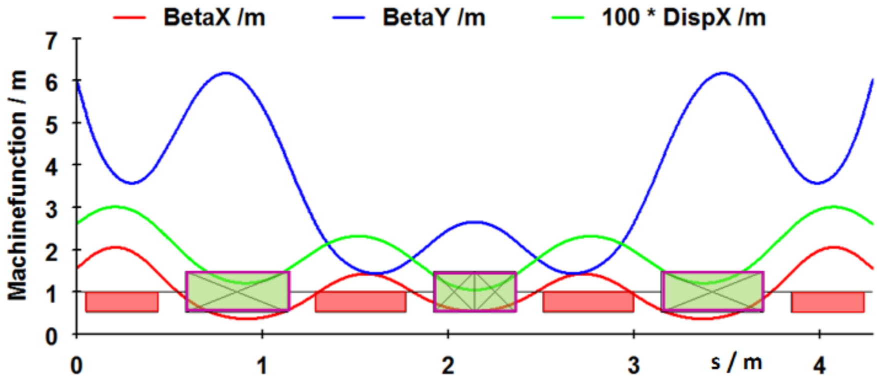


Fig. 5.4: The machine functions in more detail for the middle part of the achromat

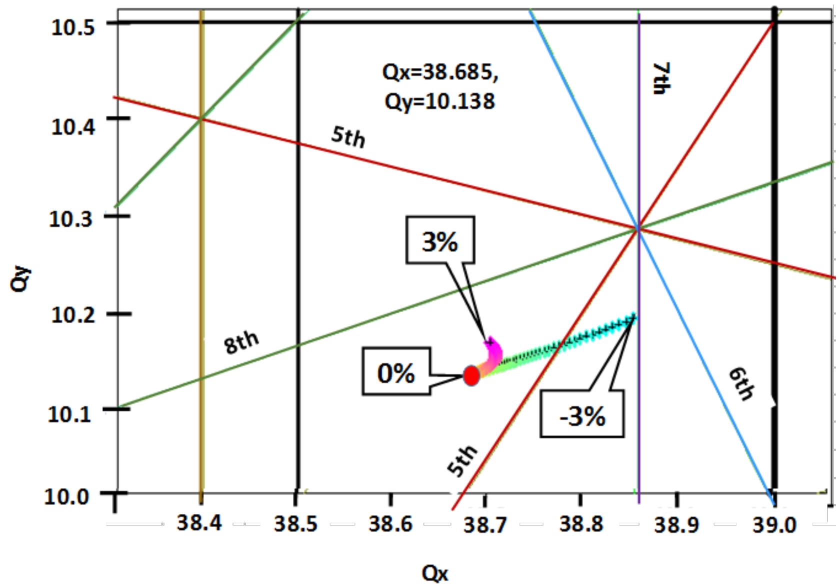


Fig. 5.5: The working point with the tunes as a function of energy deviation

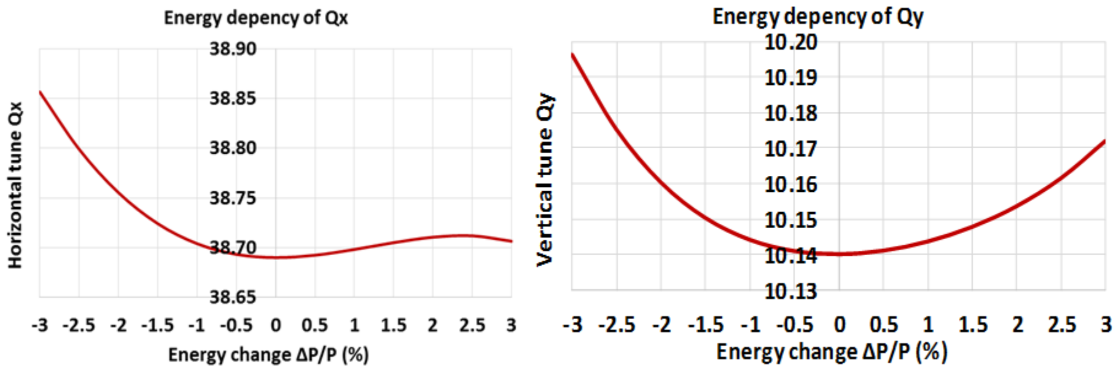


Fig. 5.6: The energy dependence of the tune shift in the horizontal (left-hand side) and vertical (right-hand side) directions.

The dynamic apertures for energy deviations ($\Delta E/E$) of up to ±3% are presented in Fig. 5.7 for the bare lattice without any misalignments and errors of the magnets. Values of ±7–8 mm should be sufficient for a high-efficiency injection.

The cross-sections of the beam, $\sigma(x)$ and $\sigma(y)$, within one achromat are displayed in Fig. 5.8 (where $\sigma(y)$ is magnified by a factor of 10). The cross-sections of the beam in the middle of the straight sections are $\sigma(x)$ = 51.2 µm and $\sigma(y)$ = 4.7 µm. Within the DBA sections the cross-sections have a maximum, and in the middle of the achromat they have a minimum.

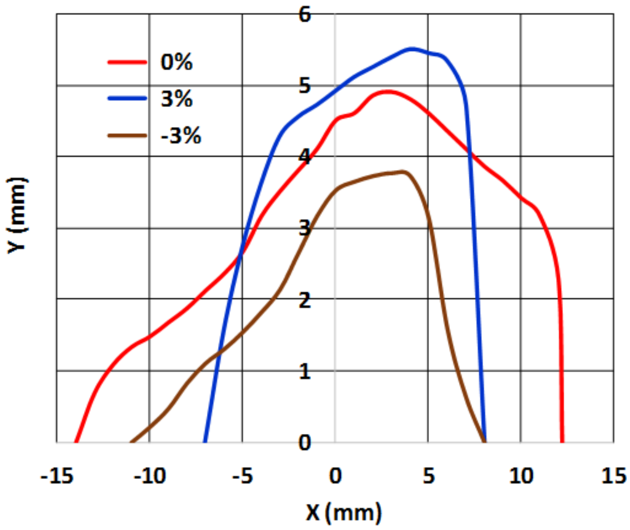


Fig. 5.7: Dynamic aperture of the HMBA lattice for energy deviations up to ±3%

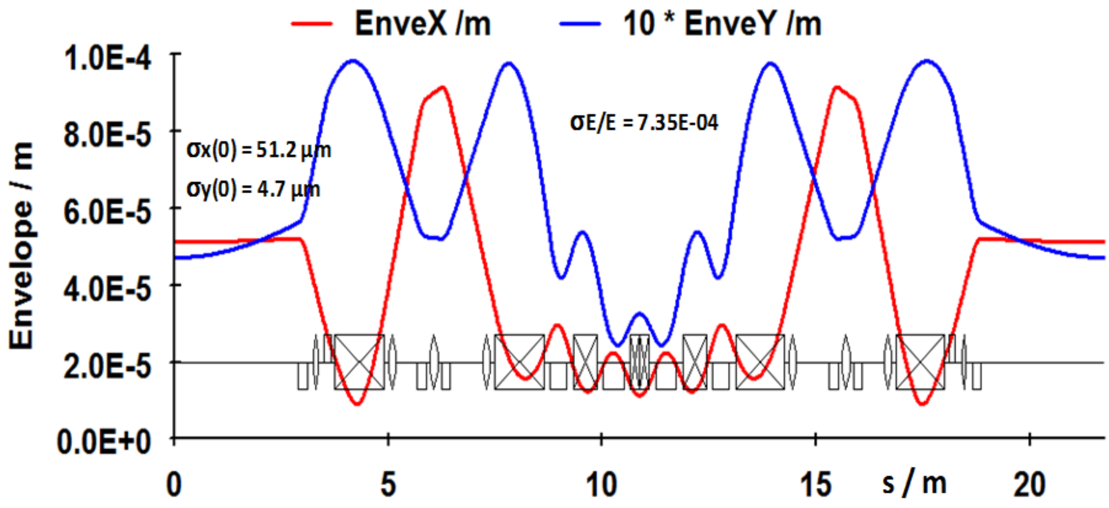


Fig. 5.8: The horizontal and vertical cross-sections of the beam within an achromat (the vertical one is enlarged by a factor of 10).

To check if there is still some room for optimization of the lattice, the contributions of the bending magnets to the emittance are calculated. The corresponding numbers are M11 = 17.1%, M12 = 14.9%, MQ1 = 12.6%, and MQ2 = 10.8% (see Fig. 5.9). This shows that the deflection angle of the bending magnets still needs to be optimized. Calculations show that an emittance in the vicinity of 150 pmrad can be reached but with the disadvantage that the chromaticity increases with a reduction in the dynamic aperture. Nevertheless, this optimization has to be done during the final design of the lattice.

SEEIIST: 7 HMBA, N=16, Jx=1.785								
Angle=	3.70	3.65	2.60	2.60	2.60	3.65	3.70	degrees
1.) = ∫H/ρ^3 =	16.40	13.90	12.50	13.30	12.50	13.90	16.40	*10^-08
2.) = ∫1/ρ^2 =	3.63	3.53	3.74	4.68	3.74	3.53	3.63	*10^-03
1.) / 2.) =	4.52	3.94	3.34	2.84	3.34	3.94	4.52	*10^-05
SUM = [1.)/ 2.)]/Jx=				14.81	*10^-05			
Magn. Contribut.:	17.09	14.90	12.64	10.82	12.64	14.90	17.09	%
			Sum =	100.1	%			

Fig. 5.9: The contributions of the different magnets to the emittance

A comparison of the SEE-LS lattice design with other light sources can be done via a plot [5.1] of the emittance divided by the normalized energy as a function of the circumference. Such a plot is presented in Fig. 5.10, including the machines of the 3rd and 4th generations. SEE-LS is represented by a white circle. Because of the reduced number of achromats given by the circumference, SEE-LS is well situated within the range of 4th generation light sources. This means that SEE-LS will indeed be a 4th generation light source.

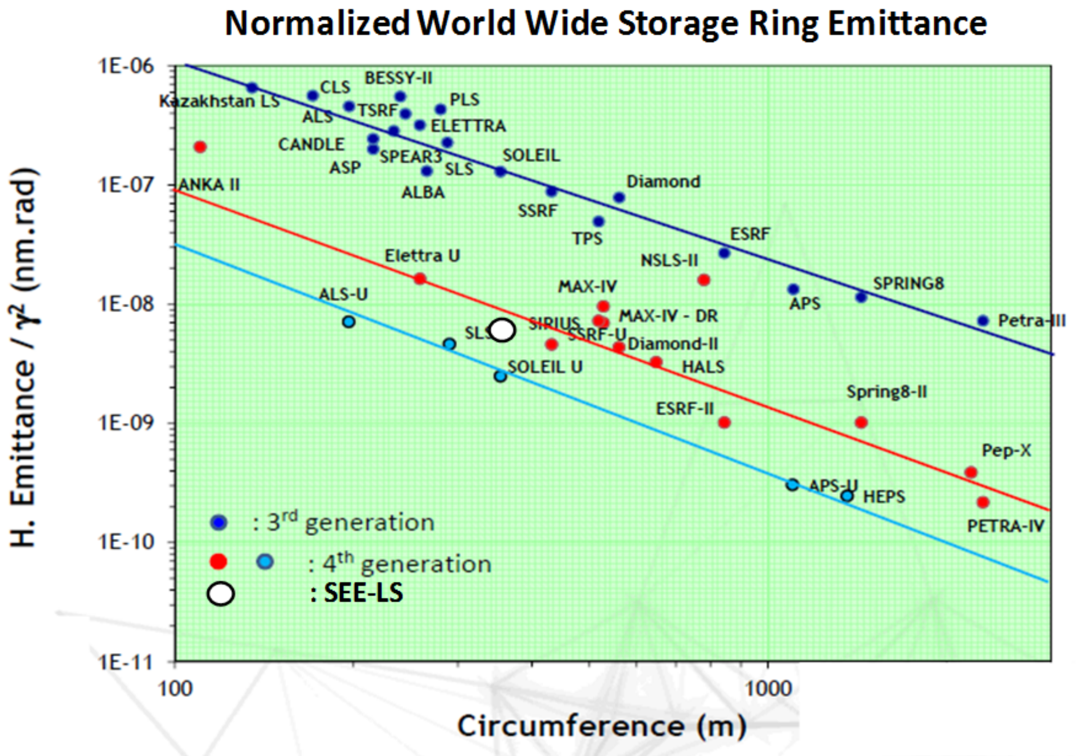


Fig. 5.10: Normalized worldwide storage ring emittances

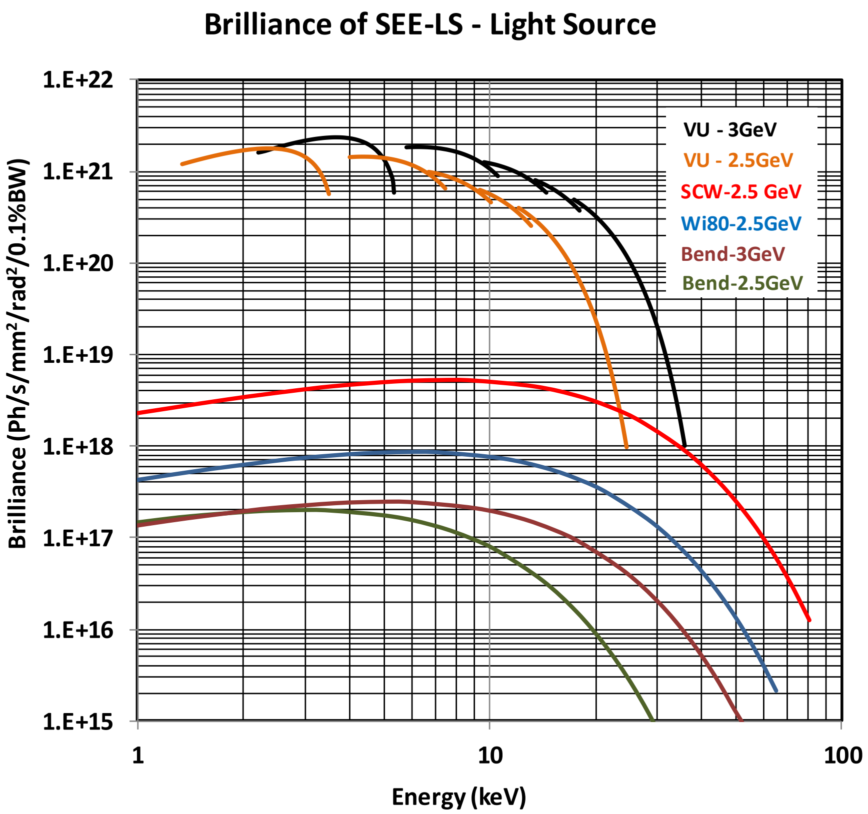


Fig. 5.11: The brilliance of SEE-LS for different energies and insertion devices

The brilliance and fraction of coherent light of the photon beam are plotted in Figs. 5.11 and 5.12, respectively. The brilliance has been calculated for different insertion devices (vacuum undulators, superconducting wigglers, and classical wigglers) as well as for different energies. The coherence increases considerably upon decreasing the emittance from 4 to 0.2 nmrad; but further decreasing the emittance to 0.1 nmrad has only a small effect on the fraction of coherent light.

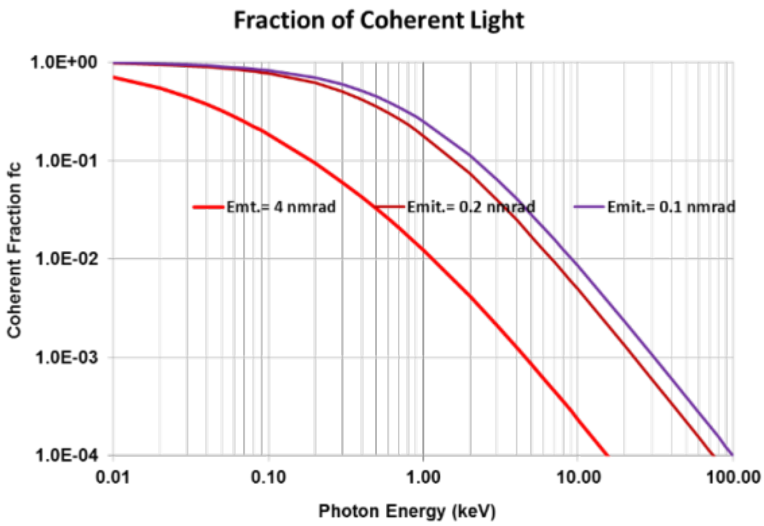


Fig. 5.12: The coherence of SEE-LS for different energies and insertion devices

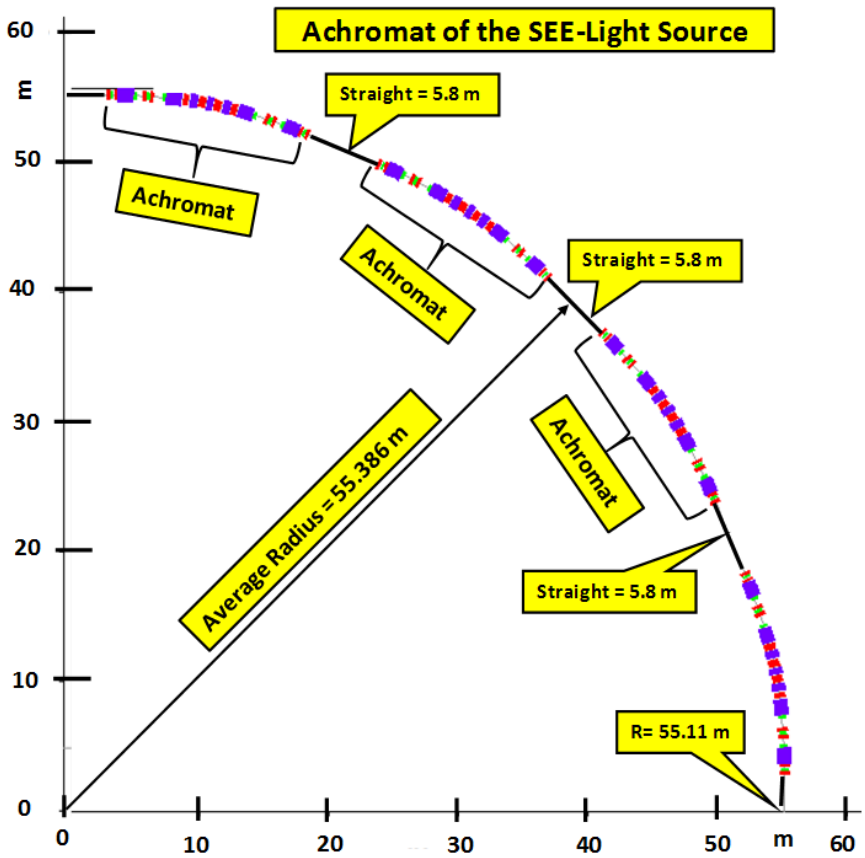
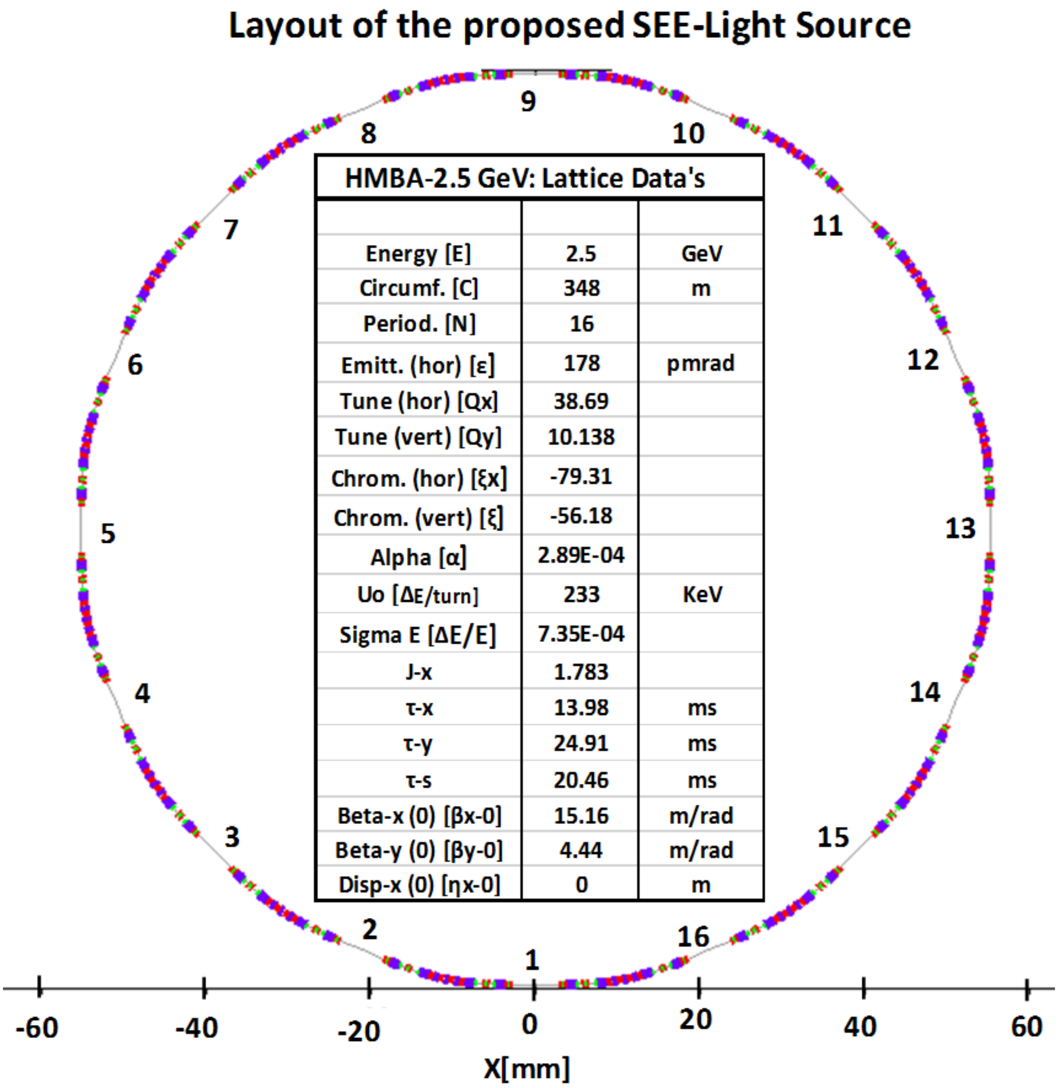


Fig. 5.13: The layout of one achromat of the storage ring

5.3 Layout of the proposed SEE-LS

The layout of one quadrant of the SEE-LS with four achromats and four straight sections is presented in Fig. 5.13. The average radius is 55.4 m and the length of the straight sections is 5.8 m. The layout of the whole machine, along with the main accelerator parameters, is presented in Fig. 5.14.



Energy [E]	2.5	GeV
Circumf. [C]	348	m
Period. [N]	16	
Emitt. (hor) [ε]	178	pmrad
Tune (hor) [Qx]	38.69	
Tune (vert) [Qy]	10.138	
Chrom. (hor) [ξx]	-79.31	
Chrom. (vert) [ξ]	-56.18	
Alpha [α]	2.89E-04	
Uo [ΔE/turn]	233	KeV
Sigma E [ΔE/E]	7.35E-04	
J-x	1.783	
τ-x	13.98	ms
τ-y	24.91	ms
τ-s	20.46	ms
Beta-x (0) [βx-0]	15.16	m/rad
Beta-y (0) [βy-0]	4.44	m/rad
Disp-x (0) [ηx-0]	0	m

Fig. 5.14: The layout of the storage ring together with the main parameters of the proposed lattice for the SEE-LS.

5.4 Specification of the magnets and RF system

The magnet structure within an achromat of the proposed lattice for the SEE-LS is presented in Fig. 5.15 and the specifications of the magnets are given in Table 5.1.

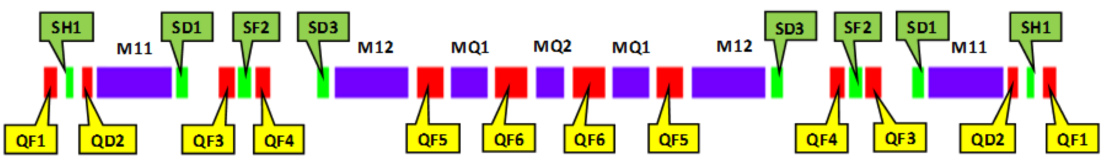


Fig. 5.15: The magnet structure within an achromat of the proposed lattice for the SEE-LS

Table 5.1: Parameters of the magnets

Element	Length (m)	Defl.-angle (degrees)	Radius (m)	Gradient (T/m)	***B*″** (T/m^2)	*B*(pole) (T)
M11	1.15	3.7	17.8081	4.3196	−91.462	0.468
M12	1.15	3.65	18.0521	9.14788	126.436	0.462
MQ1	0.55	2.6	12.1203	29.2115	−1805.9	
MQ2	0.44	2.6	9.69621	32.1468	1448.82	
		k-value	(mm)			
QF1	0.2	4.4228	16.4	36.882		0.605
QD2	0.15	−2.7487	16.4	−24.921		−0.376
QF3	0.212	2.949	16.4	24.592		0.403
QF4	0.212	3.1092	16.4	25.928		0.425
QF5	0.388	6.6183	12.7	55.190		0.701
QF6	0.484	5.8611	12.7	48.876		0.621
		M-value	(mm)			
SH1	0.1	43.448	19.2		724.631	0.1308
SD1	0.166	4.299	19.2		71.6993	0.01294
SF2	0.2	77.398	19.2		1290.85	0.233
SD3	0.166	−150.01	19.2		−2501.9	−0.4516

5.4.1 Specification of the magnet system

The bending magnets are running at a field of 0.47 T, with a gradient of up to 10 T/m; the sextupole component with roughly 2000 T/m^2 is new, and experts of the ESRF [5.2] are sure that this should be possible with permanent magnets. MQ1 and MQ2 are special magnets with a higher field, gradient, and sextupole component. The quadrupoles QF1 to QF6 have a modest gradient and no sextupole component. The sextupoles have a modest sextupole component too.

For the design of the magnets the space required in the vertical direction has to be evaluated. Space in the vertical direction is needed to capture the off-energy particles. The corresponding plot is presented in Fig. 5.16, showing the dispersion function magnified by a factor of 100. The required space in the vertical direction is given by $\eta(\Delta E/E)$. For Fig. 5.16, a safety factor of $F = 1.5$ has been introduced as well. The result is that at the beginning and end of the achromat a good field region of up to ±12 mm is needed, and in the middle a region of ±6 mm is needed.

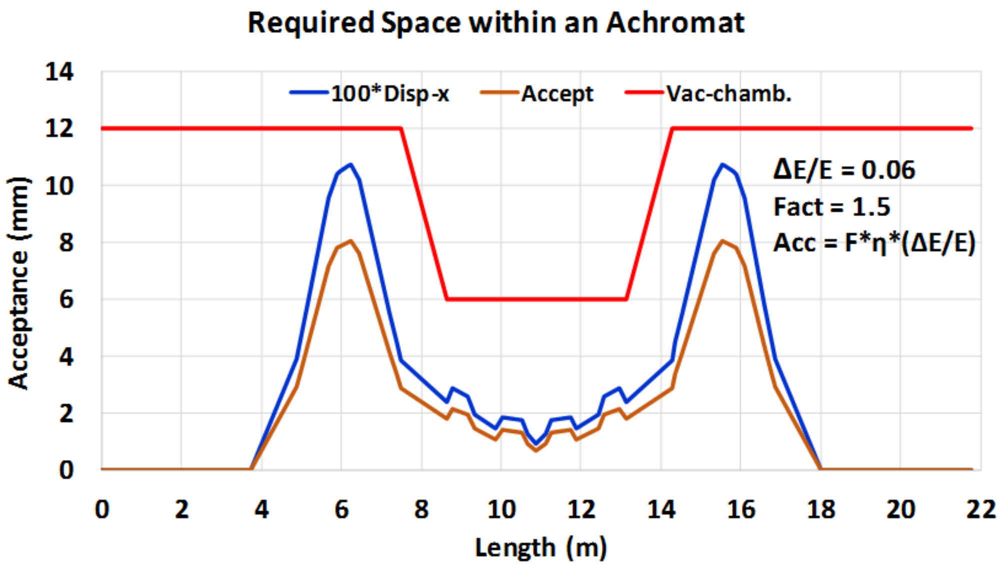


Fig. 5.16: The required space within the magnets of the SEE-LS

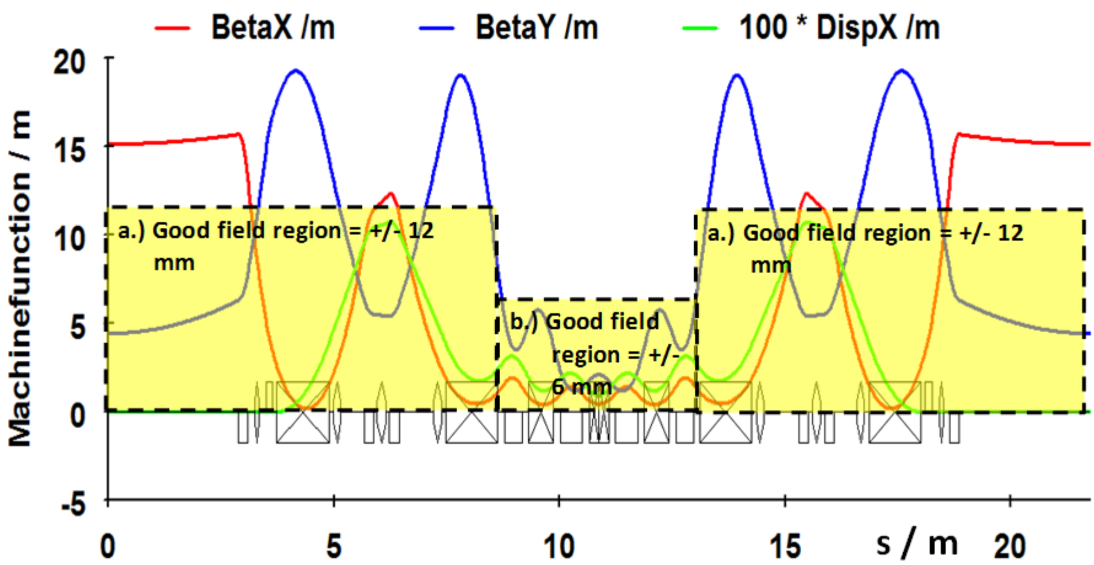


Fig. 5.17: Required space for the two regions: a) at the beginning and the end of the lattice; b) in the middle part

The middle part includes the quadrupoles QF5 and QF6 as well the bending magnets MQ1 and MQ2 (see Figs. 5.15 and 5.17).

5.4.2 Specification of the RF system

The frequency of the RF system should be 100 MHz in order to increase the bunch length and correspondingly the lifetime. The intention is to use a copy of the 100 MHz MAX IV RF system. A further advantage is that the required amplifiers are commercially available. The main parameters for the RF system are given in Table 5.2.

Table 5.2: Parameters for the design of the RF system (r.m.s. is the root mean square value)

Parameter		Value	Unit
Energy	E	2.50	GeV
Current	I_o	400.00	mA
Circumference	C	348.00	m
Momentum compaction	α	2.880E-04	
Energy loos per turn	U_o	0.233	MeV
RF frequency	F_{rf}	100.00	MHz
RF harmonic number	h	116	
Peak effective RF voltage	V_{rf}	1.40	MV
Overvoltage factor	q	6.00	
Bucket size	ε_{max}/E	0.090	
Synchrotron phase angle	Φ_s	9.60	degree
Synchrotron frequency	Ω_s	9.28	kHz
Natural r.m.s. energy spread	$\sigma E/E$	7.14E-04	
Bunch current in multi-bunch mode	I_b	3.45	mA
R.m.s. bunch length at zero current	σ_{so}	6.65	mm
R.m.s. bunch length at zero current	σ_{so}	22.17	psec
Peak current in multi-bunch mode		72.04	A
Vacuum chamber half-height	b	8.00	mm
Vacuum chamber half-width	h	11.00	mm
Vacuum chamber cut-off frequency	$\omega c = c/b$	37.47	GHz

5.5 Lifetime of the stored beam

5.5.1 Introduction

The requirements of users are good stability, a small cross-section, and a long lifetime of the beam. The desire for a small cross-section and the desire for a long lifetime of the beam are contradictory, because the Touschek lifetime goes with the cross-section of the beam. The lifetime of the stored beam is determined by the cross-section of the different processes of interaction of the stored beam with the atoms and molecules within the vacuum chamber. These processes are: 1) elastic scattering of the beam at the nucleus (Coulomb scattering); 2) inelastic scattering at the nucleus (bremsstrahlung); 3) elastic scattering at the bounded electrons of the atoms and molecules; 4) inelastic scattering at the bounded electrons of the atoms and molecules; and 5) Touschek lifetime [5.3−5.7].

The lifetime τ according to an exchange process is given by

$$\tau = \frac{1}{\sigma \cdot n \cdot c} , \qquad (5.1)$$

where:

σ is the cross-section of the exchange process;

n is the particle density within the vacuum chamber;

c is the speed of light (2.9989×10^8 ms^{-1}).

The pressure in the vacuum chamber gives the density n:

$$n = 3.22 \times 10^{22}\,\mathrm{m}^{-3} \cdot (p/\mathrm{Torr})\, n_z\,, \tag{5.2}$$

where n_z is the number of atoms per molecule.

Substituting c and n into Eq. (5.1) gives the lifetime

$$\tau = \frac{1.04 \times 10^{-18}\ \mathrm{s\,cm}^2}{\sigma (p/\mathrm{Torr})\, n_z} = \frac{2.88 \times 10^{-22}\ \mathrm{hours}}{(\sigma/\mathrm{cm}^2)(p/\mathrm{Torr})\, n_z}\ . \tag{5.3}$$

The calculation of the cross-sections of the different exchange processes will be performed below.

5.5.2 Elastic scattering at the nucleus (Coulomb scattering)

The cross-section for this exchange process is

$$\sigma_{\mathrm{Coul}} = \frac{2}{\gamma^2} \pi r_{\mathrm{e}}^2 Z^2 \left\{ \frac{\langle \beta_x \rangle \beta_{x,0}}{A_x^2} + \frac{\langle \beta_y \rangle \beta_{y,0}}{A_y^2} \right\}, \tag{5.4}$$

where:

r_{e} is the classical electron radius (2.82×10^{-13} cm);

Z is the charge of the nucleus;

γ is the normalized or reduced energy (1957(E/GeV));

A is the aperture;

$\beta_{i,0}$ is the beta functio, where the aperture has a minimum;

β_i is the average beta function.

Upon substituting the values of π and the classical electron radius into Eq. (5.4), the cross-section is given by

$$\sigma_{\mathrm{Coul}} = 2.50 \times 10^{-25}\,\mathrm{cm}^2 \cdot \frac{2Z^2}{\gamma^2} \left\{ \frac{\langle \beta_x \rangle \beta_{x,0}}{A_x^2} + \frac{\langle \beta_y \rangle \beta_{y,0}}{A_y^2} \right\}. \tag{5.5}$$

From Eqs. (5.3) and (5.5), the lifetime for Coulomb scattering is

$$\tau_{\mathrm{Coul}} = 2.21 \times 10^{9}\ \mathrm{hours} \cdot \frac{(E/\mathrm{GeV})^2}{Z^2 (p/\mathrm{nTorr})\, n_z} \left\{ \frac{\langle \beta_x \rangle \beta_{x,0}}{A_x^2} + \frac{\langle \beta_y \rangle \beta_{y,0}}{A_y^2} \right\}^{-1}\ . \tag{5.6}$$

With the data $\langle \beta_x \rangle$ = 7.0 m/rad, $\beta_{x,0}$ = 15.2 m/rad, $\langle \beta_y \rangle$ = 8.79 m/rad, $\beta_{y,0}$ = 19.44 m/rad, A_x = 10 mm, A_y = 10 mm, Z = 7, n_z = 2, and p = 2 nTorr, the lifetime is

$$\tau_{\mathrm{Coul}} = 23.3\ \mathrm{hours}\ .$$

The Coulomb scattering lifetime is proportional to the square of the energy. Changing the energy from 2.5 to 3.0 GeV would increase the lifetime by a factor of 1.44 to 33.6 hours.

In order to reach an SEE-LS lifetime of more than 40 hours, the pressure should be less than 1 nTorr.

5.5.3 Inelastic scattering at the nucleus (bremsstrahlung)

The cross-section for the inelastic scattering at the nucleus is:

$$\sigma_{\text{Brems}} = \frac{16}{411\pi} \cdot \pi r_e^2 Z^2 \ln\left(\frac{183}{Z^{1/3}}\right) \cdot \left\{ \ln\left(\frac{1}{(\delta E/E)_{\text{rf}}}\right) - \frac{5}{8} \right\}. \tag{5.7}$$

After substituting values for all the constants in Eq. (5.7), the cross-section becomes

$$\sigma_{\text{Brems}} = 3.10 \times 10^{-27}\ \text{cm}^2 \cdot Z^2 \ln\left(\frac{183}{Z^{1/3}}\right) \cdot \left\{ \ln\left(\frac{1}{(\delta E/E)_{\text{rf}}}\right) - \frac{5}{8} \right\}. \tag{5.8}$$

Thus the lifetime for the bremsstrahlung is

$$\tau_{\text{Brems}} = \frac{9.29 \times 10^4\ \text{hours}}{(p/\text{nTorr})\, n_z Z^2 \ln\left(\frac{183}{Z^{1/3}}\right)} \cdot \left\{ \ln\left(\frac{1}{(\delta E/E)_{\text{rf}}}\right) - \frac{5}{8} \right\}^{-1}. \tag{5.9}$$

With $Z = 7$ the lifetime will be

$$\tau_{\text{Brems}} = \frac{415.6\ \text{hours}}{(p/\text{nTorr})\, n_z} \cdot \left\{ \ln\left(\frac{1}{(\delta E/E)_{\text{rf}}}\right) - \frac{5}{8} \right\}^{-1}. \tag{5.10}$$

With an energy acceptance of 4.0% for the RF system, $n_z = 2$, and a pressure of 2 nTorr, the lifetime for the bremsstrahlung is

$$\tau_{\text{Brems}} = 40.1\ \text{hours}.$$

To strongly influence the lifetime of the bremsstrahlung, it is only possible to decrease the pressure. With a pressure of 1 nTorr the lifetime would be doubled to 80.2 hours.

5.5.4 Elastic scattering at the shelf electrons

The electrons of the stored beam can be scattered at the bounded electrons of the atoms and molecules. During this process energy from the stored electrons is transferred to the shelf electrons. If this energy is larger than the energy acceptance of the RF system, the scattered electrons will be lost. The cross-section for the elastic scattering at the shelf electrons of the atoms and molecules is given by

$$\sigma_{\text{Coul}}(e) = \frac{2}{\gamma} \cdot \pi r_e^2 Z \cdot \frac{1}{(\delta E/E)_{\text{rf}}} = 3.181 \times 10^{-25}\ \text{cm}^2 \frac{Z}{\gamma} \cdot \frac{1}{(\delta E/E)_{\text{rf}}}. \tag{5.11}$$

Substituting Eq. (5.11) into Eq. (5.3) gives the corresponding lifetime:

$$\tau_{\text{Coul}}(e) = 1.128 \times 10^4\ \text{hours} \frac{(E/\text{GeV})(\varepsilon_{\text{rf}}/\%)}{Z(p/\text{Torr})\, n_z}. \tag{5.12}$$

For an energy of 2.5 GeV, a pressure of 2 nTorr, $Z = 7$, $n_z = 2$, and an energy acceptance of 4%, the lifetime will be

$$\tau_{\text{Coul}}(e) = 40.3\ \text{hours}. \tag{5.13}$$

On decreasing the pressure the lifetime would go up.

5.5.5 Inelastic scattering at the shelf electrons

This is the same process as described in section 5.5.3, but the stored electrons will be scattered at the shelf electrons of the atoms or molecules. The corresponding cross-section is

$$\sigma_{\text{Brems}}(e) = \frac{16}{411\pi} \cdot \pi r_e^2 Z \cdot \left\{ \ln\left(\frac{2.5\gamma}{(\delta E/E)_{\text{rf}}}\right) - 1.4 \right\} \cdot \left\{ \ln\left(\frac{1}{(\delta e/E)_{\text{rf}}}\right) - \frac{5}{8} \right\}. \tag{5.14}$$

Upon substituting values for the constants the cross-section becomes

$$\sigma_{\text{Brems}}(e) = 3.10\times10^{-27}\ \text{cm}^2\ Z\cdot\left\{\ln\left(\frac{2.5\gamma}{(\delta E/E)_{\text{rf}}}\right)-1.4\right\}\cdot\left\{\ln\left(\frac{1}{(\delta e/E)_{\text{rf}}}\right)-\frac{5}{8}\right\}\ . \tag{5.15}$$

The corresponding lifetime is

$$\tau_{\text{Brems}}(e) = \frac{9.30\times10^4\ \text{hours}}{Z(p/\text{nTorr})\,n_z}\cdot\left\{\ln\left(\frac{2.5\gamma}{(\delta E/E)_{\text{rf}}}\right)-1.4\right\}^{-1}\cdot\left\{\ln\left(\frac{1}{(\delta e/E)_{\text{rf}}}\right)-\frac{5}{8}\right\}^{-1}\ . \tag{5.16}$$

For an energy of 2.5 GeV, a pressure of 2 nTorr, $Z = 7$, $n_z = 2$, and an energy acceptance of 4%, the lifetime will be

$$\tau_{\text{Brems}}(e) = \frac{9.30\times10^4\ \text{hours}}{7\times2\times2}\cdot\{12.63-1.4\}^{-1}\cdot\{3.22-0.625\}^{-1}\ , \tag{5.17}$$

that is,

$$\tau_{\text{Brems}} = 114\ \text{hours}\ . \tag{5.18}$$

5.5.6 Touschek lifetime

Within the bunches the electrons perform movements, and this leads to scattering between the stored electrons within one bunch. This scattering process has to be treated as Coulomb scattering. The lifetime of this so-called Touschek effect is given by

$$\tau_{\text{Tou}} = \frac{8\pi\gamma^2\sigma_x\sigma_y\sigma_l\varepsilon_{\text{acc}}^3}{r_{\text{e}}^2cN_{\text{e}}}\cdot\frac{1}{D(\xi)}\ . \tag{5.19}$$

In terms of the bunch volume $V_{\text{B}} = (4\pi)^{3/2}\sigma_x\sigma_y\sigma_l$ the Touschek lifetime is

$$\tau_{\text{Tou}} = \frac{8\pi\gamma^2 V_{\text{B}}\,\varepsilon_{\text{acc}}^3}{(4\pi)^{3/2}r_{\text{e}}^2cN_{\text{e}}}\cdot\frac{1}{D(\xi)}\ . \tag{5.20}$$

Upon substituting values for the constants, Eq. (5.20) becomes

$$\tau_{\text{Tou}} = 6.57\times10^7\ \text{hours}\,\frac{(V_{\text{B}}/\text{mm}^3)\gamma^2\,\varepsilon_{\text{acc}}^3}{N_{\text{e}}}\cdot\frac{1}{D(\xi)}\ . \tag{5.21}$$

where:

- σ_x is the average cross-section in the horizontal direction;
- σ_y is the average cross-section in the vertical direction;
- σ_l is the average cross-section in the longitudinal direction;
- V_{B} is the bunch volume;
- ε_{acc} is the energy acceptance of the accelerator, which is normally the energy acceptance of the RF system;
- ξ is the normalized function $(\varepsilon_{\text{acc}}/\gamma\sigma'_x)^2$, with $\sigma'_x = \varepsilon_x\gamma_x + \eta'^2(\sigma_{\text{E}}/E)^2$ being the maximum slope of the stored electrons;
- $D(\xi)$ is a normalized function.

The function $D(\xi)$ is plotted in Fig. 5.18. Upon inserting the values of the constants into Eq. (5.21), the Touschek lifetime will be

$$\tau_{\text{Tou}} = 0.538\ \text{hours}\ \frac{hf(E/\text{GeV})(\sigma_x/\text{mm})(\sigma_y/\text{mm})(\sigma_l/\text{mm})(\varepsilon_{\text{acc}}^3/\%)^3}{(I/\text{A})(C/\text{m})D(\xi)}\ . \tag{5.22}$$

where f is the filling factor and C is the circumference in metres.

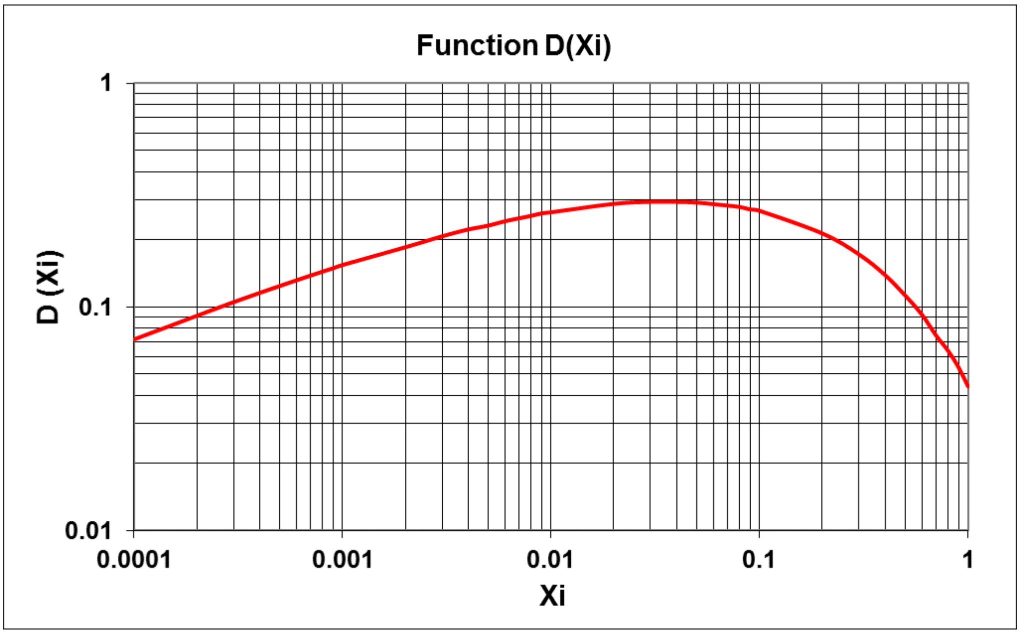


Fig. 5.18: The function $D(\xi)$ for the calculation of the Touschek lifetime

For SEE-LS we have the following data: E/GeV = 2.5, h = 116, C/m = 348, I/A = 0.4, f = 0.8, $\langle \sigma_x / \text{mm} \rangle = 0.465$, $\langle \sigma_y / \text{mm} \rangle = 0.040$, $\sigma_l / \text{mm} = 9$, ε_x/pmrad =178, $\langle \gamma_x \rangle = 1.5$, $(\eta')_{\max} = -0.4$, σ_E/E = 0.00074, $\langle \sigma'_x \rangle = 0.00003\ \text{rad}$, $\langle \xi \rangle = 0.0027$, ε_{acc} = 4.0%, $D(\xi)$ = 0.2.

With these values, the Touschek lifetime will be

$$\tau_{\text{Tou}} = 1.6 \text{ hours} . \qquad (5.23)$$

If a third harmonic cavity is used, the bunch length would increase to 42 mm with a Touschek lifetime of 7.2 hours. Because users require a long beam lifetime, it is expected that third-harmonic cavities will have to be used.

5.5.7 Conclusions regarding beam lifetime

The total lifetime of the stored beam is given by

$$\frac{1}{\tau_{\text{Total}}} = \frac{1}{\tau_{\text{Coul}}(N)} + \frac{1}{\tau_{\text{Brems}}(N)} + \frac{1}{\tau_{\text{Coul}}(e)} + \frac{1}{\tau_{\text{Brems}}(e)} + \frac{1}{\tau_{\text{Tou}}} . \qquad (5.24)$$

The values of the total lifetime are summarized in Table 5.3 for pressures of 2 and 1 nTorr.

Table 5.3: Lifetimes for the different interaction processes

	$\tau_{\text{Coul}}(N)$	$\tau_{\text{Brems}}(N)$	$\tau_{\text{Coul}}(e)$	$\tau_{\text{Brems}}(e)$	τ_{Tou}	τ_{Total}
P = 2 nTorr	23.3 h	40.1 h	40.3 h	114 h	7.2 h	4.2 h
P = 1 nTorr	46.6 h	80.1 h	80.6 h	227 h	7.2 h	5.2 h

According to Table 5.3, the overall lifetime is determined by the Touschek effect. To achieve a lifetime in the range of 10 hours the pressure should be smaller than 1 nTorr.

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