DESIGN OF A DAMPING RING FOR THE SB-LINEAR-COLLIDER PROJECT AT DESY

R. Brinkmann[1], D. Einfeld[2], M. Plesko[3], J. Schaper[2]
[1]DESY, Notkestr. 85, D-22607 Hamburg, Germany
[2]Fachhochschule Ostfriesland, Constantiapl. 4, D-26723 Emden, Germany
[3]J. Stefan Institute, Jamova 39, SLO-1001 Ljubljana, Slovenia

Abstract

For the SB-Linear-Collider project (SBLC) at DESY a redesign of the damping ring has been performed, mainly in order to optimise the dynamic aperture. The lattice of the proposed damping ring has a DBA structure, similar to the 3rd generation light sources ESRF, APS and SPRING-8. The damping ring is build up with 6 superperiods. The straight sections between these periods are used for the injection, ejection and rf-cavities. In turn, each superperiod consists of 6 DBA cells. The straight sections of these cells are used for the installation of the wigglers, which are needed for the damping. With the installation of overall 150 m of wigglers (B_0 = 2 T and λ_0 = 0.2 m) the equilibrium emittances are $\varepsilon_{x,0}$ = $6.5 \cdot 10^{-10}$ $m \cdot rad$ and $\varepsilon_{y,0}$ = $1.3 \cdot 10^{-11}$ $m \cdot rad$ (the corresponding normalised emittances are : $\varepsilon_{x,n}$ = $3.8 \cdot 10^{-6}$ $m \cdot rad$ and $\varepsilon_{y,0}$ = $7.6 \cdot 10^{-8}$ $m \cdot rad$. The damping time results in $\tau_y \leq$ 3.4 ms. The dynamic acceptance including misalignment and magnet errors is in the range of $A_x \leq$ 72 $mm \cdot mrad$ and $A_y \leq$ 80 $mm \cdot mrad$.

1 INTRODUCTION

1.1 General

High luminosity in linear colliders can only be reached by damping the beam in a so called damping ring before it is accelerated to high energies. For the S-Band-Linear-Collider project (SBLC) at DESY[1] the beam has to be damped to normalised emittances $\varepsilon_{x,n} < 5 \cdot 10^{-6}$ $m \cdot rad$ and $\varepsilon_{y,n} < 2.5 \cdot 10^{-7}$ $m \cdot rad$ within a time of 19.6 ms corresponding to the repetition frequency of 50 Hz. According to the pulse structure within the linacs (2 μs) the circumference of the damping ring has to be larger than 600 m. The current within one pulse should be 300 mA. In order to reach these parameters the damping ring must have a sufficient dynamic aperture for the injection process and a sufficient lifetime. To meet the requirements on the damping time, damping wigglers have to be introduced. Conventionally, such a ring is realized by a racetrack structure[2][3][4]: two arcs with bends and two long straight sections that accommodate the damping wigglers, injection, extraction and the RF-system. In such a scheme the dynamic aperture is drastically reduced by introducing the long straight sections for the damping wigglers.

In comparison to these design the 3rd generation light sources like ESRF, APS, ALS, ELETTRA[5] etc., have a relatively large dynamic aperture. Investigations at these projects have shown that the installation of insertion devices doesn't reduce the dynamic aperture very much.

1.2 Damping Ring Requirements

The damping of the emittance within a storage ring is,

$$\varepsilon_f = \varepsilon_{inj} \cdot e^{-2t/\tau_D} + \varepsilon_{equ} \cdot (1 - e^{-2t/\tau_D}) \qquad (1)$$

where ε_f is the final emittance, ε_{inj} that one of the injected beam and ε_{equ} is the equilibrium emittance of the damping ring. τ_D is the damping time of the ring and t is the accumulation time within the ring, t = 19.6 ms.

The evaluation of Eq. (1) gives for the damping ring the following requirements: $\varepsilon_{x,n}$ = $4 \cdot 10^{-6}$ $m \cdot rad$, $\varepsilon_{y,n}$ = $2 \cdot 10^{-7}$ $m \cdot rad$, $\tau_D \leq$ 3.5 ms.

Here, an emittance dilution budget of 25% from the damping ring to the IP is taken into account. The energy of the damping ring should be in the range between 2.5 and 3.5 GeV. At an energy of 3 GeV the normalised emittance of $4 \cdot 10^{-6}$ $m \cdot rad$ translates into an absolute horizontal emittance of $6.7 \cdot 10^{-10}$ $m \cdot rad$ which is the domain for a fourth generation light source, about an order of magnitude below existing third generation light sources.

The small emittance of the injected electron beam ($\varepsilon_{x,n}$ = $1 \cdot 10^{-4}$ $m \cdot rad$) results in a relaxed dynamic aperture ($\approx$ 10 $\pi \cdot mm \cdot mrad$ for the electron damping ring (DR). Quite different is the situation for the positron DR. The emittance of $1 \cdot 10^{-2}$ $\pi \cdot mm \cdot rad$ results in a beam size at injection of 5 mm. According to the fast damping ($\tau_D \leq$ 3.5 ms) this value will be damped within 3.5 ms down to 1.8 mm. We assume that an aperture of 3 $\sigma_{x,inj}$ = 15 mm should be enough for the positron damping ring, resulting in an acceptance of 20...30 $\pi \cdot mm \cdot mrad$.

2 LATTICE

2.1 Lattice of the base ring

We took as the base of the redesign the lattice of the ESRF[6] and performed the following alterations: 1) Reduction of the circumference from 880 m to 660 m; 2) Decreasing the radius of curvature of the bending magnets in order to enhance the damping; and 3) Changing of the deflection angle from 5.625 degree to 5.0 degree in order to reduce the emittance and increase the number of straight sections from 32 to 36.

2.2 Introduction of damping wigglers

Six straight sections are needed for injection, extraction and the rf-system. With an equal distribution of them around the ring we have a sixfold symmetry. The length of a straight section - from quadrupole to quadrupole - is 6 m. With 5 m long wigglers an overall length of 150 m of wigglers can be installed. The maximum magnetic field within the wiggler has been set to 2.0 T and the period length to 0.2 m.

The wigglers have an effect on the damping time, the energy spread and the emittance. The emittance is reduced five-fold, the damping time by a factor of 7.5 and the energy spread increases by 3.1. Including the wigglers the ring has the following parameters:
$\varepsilon_{x,0}$ = $6.5 \cdot 10^{-10}\ m \cdot rad$, $\varepsilon_{y,0}$ = $0.13 \cdot 10^{-10}\ m \cdot rad$, τ_ε = 1.67 ms,τ_x = 3.34 ms, τ_y = 3.34 ms.

2.3 Damping Ring Layout

The schematic layout of the SBLC-DR is presented in Fig. 1. The DR has a sixfold symmetry and each superperiod consists of five unit cells with two matching sections. The unit cells are the normal DBA-structures with a damping wiggler in the straight section. The matching sections are the places for the injection, ejection and the rf-system. The lattice functions of the superperiod are presented in Fig. 2.

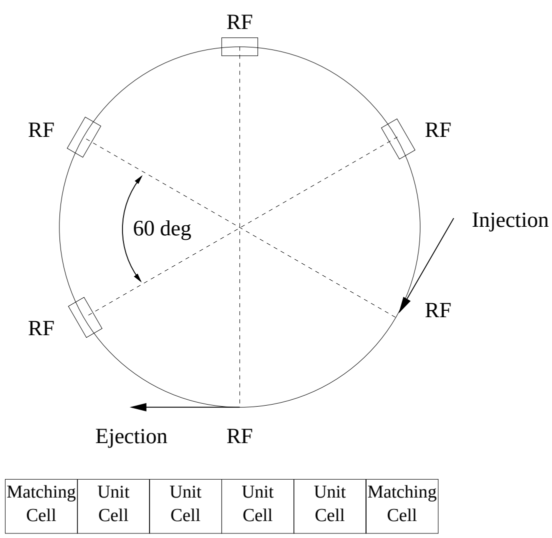

Figure 1: Schematic layout of the SBLC-DR. With a sixfold symmetry. each superperiod consists of five unit cells and two matching sections.

In order to have within the matching sections the same phase advance as within the unit cell one has to introduce in the straight section of the matching section some extra quadrupoles because the wigglers within the straight section of the unit cell perform a focusing in the vertical direction. The dynamic aperture including misalignment and some magnet errors is given in Fig. 3. At injection the aperture is a factor 5 larger as the positron beam size. This is sufficient. The energy acceptance of the DR is larger as 4%.

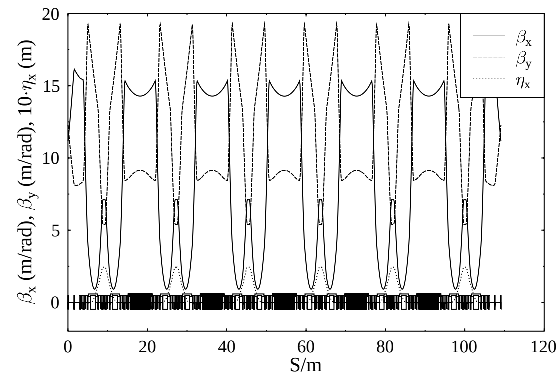

Figure 2: Lattice functions within one superperiod of the SBLC damping ring. Each superperiod consists of the unit cells with wigglers and two matching sections at each side.

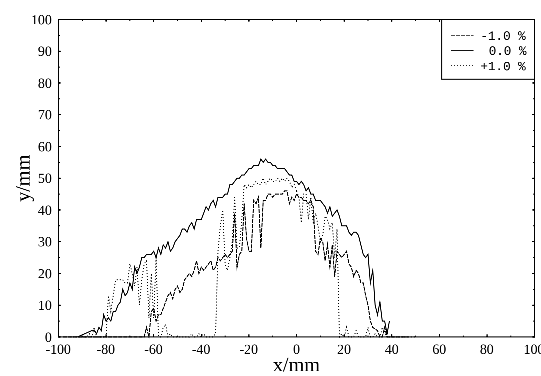

Figure 3: Dynamic aperture of the SBLC-damping ring with field errors $\Delta B/B = 5 \cdot 10^{-4}$ for the bending and $\Delta G/G = 5 \cdot 10^{-3}$ for the quads.

3 ALIGNMENT TOLERANCES AND THE VERTICAL EMITTANCE

The vertical equilibrium emittance is essentially determined by the magnet and beam position monitor (BPM) alignment tolerances and by the orbit correction procedures applied. We used the PETROS computer code to simulate alignment errors and orbit correction procedures. Assuming rms magnet and BPM position tolerances of 50 μm, the MICADO algorithm is applied in several iterations until the quality of the orbit does not improve anymore. From 10 different random seeds of errors we obtain an average vertical normalised emittance of (1.0 $\pm$ 0.9)$10^{-7}\ m \cdot rad$. So the required emittance could just be achieved with the assumed tolerances and standard correction techniques.

4 RF-SYSTEM

The layout of the RF-System is determined by the radiation loss per turn U_0 and the required energy acceptance. For the SBLC-DR U_0 = 3.95 MeV (including the damping wigglers) and the energy acceptance $(\Delta E/E)_{RF}$ should be at least 10 times the energy spread. With an overvoltage factor q = 2 the energy acceptance is 7.2%. There has to be installed an overall voltage of 7.9 MV with a beam power of P_{beam} = 1.2 MW. The number of cavities is determined by the power which can be fed through the input coupler. Currently, both normal or superconducting cavities are being considered. For the ELETTRA normal conducting cavity[7] as well as the HERA superconducting one[8] it is around 110 kW. Hence overall 10 to 12 cavities have to be installed. The CESR superconducting cavity[9] is designed for an input power up to 250 kW. Already achieved have been 150 kW. This means that 5 to 8 cavities have to be installed. The specifications of the CESR cavity are: G = 6 MV/m, V_{RF} = 1.8 MV, $Q_0 = 10^9$, (R/Q = 89 Ω/cell, $Q_L = 2 \cdot 10^5$ and $l_{eff} = 0.3m$). Taking 5 cavities with a gradient of 1.8 MV/cell the overall RF voltage leads to q = 2.6, with an RF energy acceptance of 7.2%. By taking the phase ϕ_s = 22.62 degrees, the synchrotron tune results in $\nu_s = 8.92 \cdot 10^{-3}$, $\Omega_s = 2.55 \cdot 10^4$, f_s = 9.724 kHz.

The bunch length is then, with $\sigma_E/E = 2.2 \cdot 10^{-3}$, equal to σ_z = 4.25 mm.

5 INSTABILITIES

5.1 *Single Bunch Instabilities*

The microwave instability, sometimes referred to as turbulent bunch lengthening, causes an increase in both the momentum spread and the bunch length of a bunched beam. With I_{aver} = 0.8 mA per bunch, α= $1.64 \cdot 10^{-4}$, σ_z = $4 \cdot 10^{-3}$ m, (σ_E/E) = $2.2 \cdot 10^{-3}$ and R = 104 m one gets for the broad band impedance a maximum allowed value of $[Z_n/n]$ = 0.3 Ω that would avoid the instability. According to some measurements the contribution of the vacuum chamber at ELETTRA has a value of 0.15 Ω[10]. We assume a similar value here as well. From the measured loss factor of the CESR superconducting cavity[9] a broad band impedance of 0.03 - 0.05 Ω could be determined. With 8 cavities the contribution of the RF-system to the broad band impedance is 0.24-0.4 Ω. From this we can estimate the impedance as : $[Z_n/n]$ = (0.4-0.7) Ω, which is about a factor of two larger than desirable. Taking into account the SPEAR-scaling this value reduces down to 0.06 Ω. So bunch lengthening seems to be avoidable, but not with a large safety margin and further studies of this issue are required.

5.2 *Multibunch Instabilities*

With 333 stored bunches and a total current of 300 mA, multibunch instabilities are of concern. Stability is guaranteed if $(1/\tau_{\|}) < (1/\tau_{\varepsilon})$. $1/\tau_{\|}$ is the growth rate of the longitudinal coupling bunch instability and τ_{ε} is the damping time of the synchrotron oscillations. Taking a shunt impedance of $R_{s\|}$ = 200 $k\Omega$ (which is typical for a normal conducting cavity) results in a maximum current of 136 mA. The shunt impedances of the HOM's within a CESR superconducting cavity are in the range of 0.1-0.7 $k\Omega$, leading to an instability threshold of I $>$ 380 mA. Hence the coupled bunch instability are of no importance when using superconducting cavities.

There are coupled bunch instabilities in the transverse direction, too. For a transverse impedance of $R_{\perp}$ = 11 MΩ/m (which is typical for a normal conducting cavity) the maximum stored beam within the DR is 4.0 mA. The transverse impedances of the CESR-SC-cavity are smaller than 0.025 MΩ/m leading to a threshold current of 1760 mA. In this case, however, other contributions to the impedance (in particular the resistive wall impedance) may become dominant. Whether or not a feedback system is required, must be determined by more detailed investigations. In any case it should be noted that the issue of multibunch instabilities is significantly relaxed compared to the B-factory rings presently under construction at SLAC and KEK.

6 REFERENCES

[1] Linear Collider Design Report, DESY-97-048

[2] R. Brinkmann, A Study of Low - Emittance damping ring Lattices, DESY M-90-09 (July 1990).

[3] ATF, Accelerator Test facility, Design and Study Report, Internal 95-4 (June 1995).

[4] NCL damping ring, Zeroth-Order Design Report for the next Linear Collider, SLAC, Stanford (1996).

[5] ESRF Foundation Phase Report (February 1987) European Synchrotron Radiation Facility, B.P.220-38043, Grenoble Cedex.

[6] J. Murphy, Synchrotron Light Source DATA Book, BNL/NSLS, BNL 42333, Version 4.

[7] M. Svandrlik *et al*., The Cure of Multibunch instability in ELETTRA, Proceedings of the PAC 95, Dallas, Texas, USA.

[8] R. Byrns, B. Dwersteg *et al*., Status of the Superconducting Cavity, Program for HERA, Proceedings of the EPAC 90, Nice (June 12-16, 1990).

[9] S. Belomestnyk *et al*., Wakefield and HOMs Studies of a Superconducting Cavity Mode with the CESR Beam, Proceedings of the PAC 95, Dallas, Texas, USA.

[10] J.E. Karantzoulis, The Coupling Impedance of the ELETTRA Storage Ring ST/M-TN-()/14 (August, 1990) Sincrotrone Trieste.