THE LNLS UVX2 SOFT X-RAY SOURCE

Liu Lin, L.Jahnel and P.Tavares
Laboratório Nacional de Luz Síncrotron - LNLS/CNPq
Caixa Postal 6192 - Campinas - SP - Brazil.

Abstract

The lattice design of a 1.15 GeV electron storage ring for the LNLS Soft X-Ray source is described. Discussions include different operation modes for the selected double-bend achromat lattice, in particular, a mode for small gap insertion; beam dynamics studies taking into account alignment and magnetic field errors; effects of collective instabilities on single bunch parameters and lifetime both at the operating energy and at the low injection energy and finally a conventional scheme for the low energy injection.

1. INTRODUCTION

The recommended guidelines for the LNLS VUV Soft X-Ray electron storage ring are:

- the critical photon wavelength from the bending magnets should be 10 Å;
- the lattice should include long straight sections to accommodate insertion devices, for instance high-field wigglers. If possible, the lattice should also envisage the use of micro-undulators or other small gap devices;
- the design of the magnetic elements should be conservative;
- small number of magnetic elements;
- reliable operation of the ring, which is of paramount importance. This includes low sensitivity of the lattice to errors and flexibility enough to allow for other operation modes, correction of the insertion devices effects, etc;
- feasible low energy (100 MeV) injection and
- a long (about 10 hours) electron beam lifetime.

Based on these guidelines and the machine design experience gained from the previous proposals, a new suggestion - UVX2 - is presented in this report. A complete description of the design project can be found in ref [1].

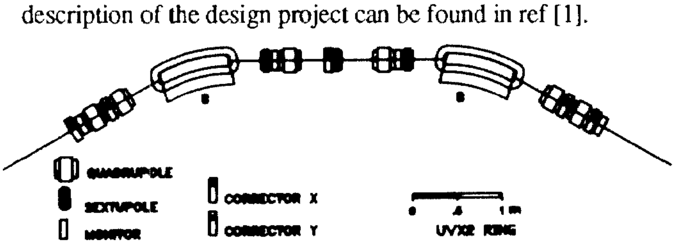

Figure 1: Lay-out of one superperiod of the 1.15 GeV UVX2 storage ring.

2. MAGNET LATTICE

The proposed solution, UVX2, is a six-fold symmetric double-bend Chasman-Green achromat lattice. See figure 1. It has twelve 1.4 Tesla rectangular bending magnets. The energy of the ring is 1.15 GeV, providing λ_c =10 Å. The achromats connect six 4-meter long dispersion-free straight sections, four of which allow for insertion devices (one is used for injection and another for the RF cavity). The double-bend achromatic arc consists of two 30 degree bending magnets separated by two horizontally focusing quadrupoles.

Two additional operation modes, a higher emittance (UVX2H) and a lower emittance (UVX2L) mode, are being investigated. The main parameters of these operation modes are listed in table I. In Section 2.1 a mode with low vertical betatron function in one of the insertion straights is presented, and the remainder of the report describes only the results for UVX2 normal operation mode. Figure 2 shows the optical functions for one superperiod of the ring. All calculations described here are done with the codes MAD[2] and PATPET[3].

Table I: Main Parameters of the UVX2 storage ring for three different operation modes.

	UVX2	UVX2H	UVX2L	
Energy		1.15		GeV
Injection energy		100		MeV
Nominal current		100		mA
Circumference		87.828		m
Magnetic structure		CG-6-fold		
Revolution frequency		3413.4		kHz
Harmonic number		146		
RF frequency		500		MHz
Natural emittance	65.3	117.0	33.9	nm.rad
Horizontal betatron tune	5.27	4.75	5.72	
Vertical betatron tune	2.17	1.85	1.85	
Momentum compaction		8.82×10^{-3}		
Natural energy spread		0.059		%
Hor. nat. chromaticity	-8.17	-5.56	-19.01	
Vert. nat. chromaticity	-9.70	-8.62	-9.23	
Hor. bet. damping time		12.5		ms
Vert. bet. damping time		11.9		ms
Bending radius		2.735		m

Two families of sextupoles, SF and SD, are used in the dispersive region for chromaticity correction. Besides these two families, two others are used in the non-dispersive region to compensate for the geometric aberration produced by the chromatic sextupoles. The latter are placed inside the quadrupole doublets on each side of the insertion straight, the sextupolar fields being achieved by additional windings in those magnets.

The inclusion of wigglers and undulators with plane poles produces a vertical betatron tune shift which must be compensated to ensure operation far from resonances. A 1 m, 2 Tesla wiggler increases the vertical tune by 0.26; and a 25 cm, 5 Tesla one by 0.40. The UVX2 lattice can be tuned to compensate a vertical tune shift of 0.55 without changing the horizontal tune.

3.1 Bunch Lengthening and Emittance Growth

The equilibrium bunch length and momentum spread is determined by the combined effects of microwave instability, potential well distortion and IBS. At 100 MeV, the bunch length grows by a factor that varies from 16 to 80 as compared to the natural value, whereas at 1.15 GeV this factor is in the range 1-3.

The equilibrium transverse emittance is determined by IBS at 100 MeV. In all considered cases, the emittance increases by about 3 orders of magnitude as compared to the natural value. At full energy, no significant additional bunch lengthening, widening or emittance growth due to IBS is observed.

3.2 Beam Lifetime

Three beam lifetime limiting processes are considered: Touschek scattering, elastic and inelastic scattering from the nuclei of residual gas molecules. The Touschek contribution to the overall lifetime is calculated using the equilibrium values of bunch length, energy spread and transverse emittances of the previous section. We find that at 100 MeV, above 180 kV RF peak voltage, the acceptance is determined by the lattice and the lifetime decreases with increasing voltage above 180 kV. In contrast, at 1.15 GeV, the limitation is the RF system and lifetime always increases with RF voltage.

Gas scattering lifetime is calculated assuming a 1 ntorr nitrogen pressure. The acceptance is determined by the dynamical aperture in the x direction and by the physical aperture in the y direction (bending magnet gap, 41 mm). At 100 MeV, the gas scattering contribution largely dominates the overall half-life, being nearly constant for all cases under consideration (~13 minutes). As a result, the overall half-life is nearly the same for all these cases (~12 minutes). At 1.15 GeV, the gas-scattering contribution is on the same order as the Touschek contribution, varying from 21 hours at 100 kV to 25 hours at 1MV. Figure 4 shows the overall half-life at 100 MeV and at 1.15 GeV against RF voltage.

We conclude that the overall lifetime is adequate, both at low and high energy. At 100 MeV, IBS guarantees that the lifetime is not reduced below the radiation damping times (few seconds). At full energy, increasing the RF voltage up to 1 MV would be beneficial, although 600 kV seems quite enough to allow for a half-life above 10 hours as originally intended.

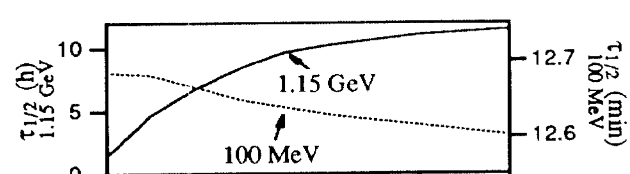

Figure 4: Overall half-life at injection and full energy against peak RF voltage for 5 mA average current in a single bunch. Broadband impedance is 13 Ω OFF.

4. LOW ENERGY INJECTION

To inject the UVX2 electron storage ring, a beam from a linear accelerator - MAIRA[8] - is used. The electrons are injected and accumulated at low energy (100 MeV). Ramping to the nominal energy follows and the final nominal current is 100 mA. The injection into the UVX2 storage ring takes place in one of the long straight sections, in the radial plane and from the inner side of the circumference. The beam is injected into the storage ring's acceptance which is locally deflected in the radial plane by three fast kickers. The kickers must be turned off in 4 turns to prevent the injected beam from colliding with the vacuum chamber wall.

Two injection modes were studied: injection with the phase ellipse parameters matched and mismatched to the ring's acceptance. The mismatched mode is optimized to fit the maximum of the injected beam into the available bumped acceptance region. This way, the efficiency of injection into the acceptance is increased from 70% to 97%. The overall injection efficiency must also include the losses in the transport line (85%) and ramping process (25%).

The time needed to accumulate 100 mA in the storage ring in a multi-bunch mode is estimated. The linac provides a 200 ns and 200 mA pulse. Injecting the pulses at intervals equal to the betatron damping time gives an injection time of 1.6 minutes in the matched mode and 1.3 minutes in the mismatched mode. These injection times are less than the beam lifetime at 100 MeV, which is about 12 minutes.

An important effect at low energy is the ion trapping by the potential well of the beam. This effect is deleterious to the performance of the ring. An ion clearing system have been dimensioned for UVX2 and is described in reference [9].

5. REFERENCES

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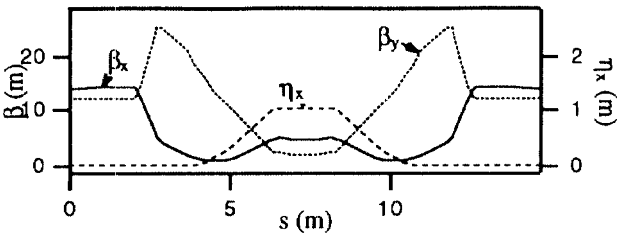

Figure 2: Optical functions along one superperiod for UVX2 normal operation mode.

2.1 *Low Vertical β Optics*

An operation mode with low vertical beta function in one of the long dispersion-free straight sections that can be achieved by continuously transferring the configuration of the lattice from the normal operation mode has been investigated. This requires that no resonance lines be crossed during the process. The proposed mode can be accomplished in this lattice by independently powering the quadrupole doublets adjacent to the low β_y straight. The vertical beta is matched to 0.60 m in the small gap insertion straight, a factor of 20 smaller than the value for the normal operation mode. Both the vertical and the radial tunes, as well as the emittance, are kept the same as in the normal operation mode. The reduction in the vertical beta in the insertion straight causes the vertical phase advance to increase across this region. To keep the same tune, the vertical phase advance over the achromat must be reduced. This is not the case in the horizontal plane: the change in horizontal beta is very small, not significantly affecting the horizontal phase advance in the achromat.

It is interesting to note that the β scaled physical aperture at the small β point is 2 x 3.4 mm; thus any gap smaller than this value will limit the vertical acceptance of the ring.

2.2 *Sensitivity to Errors and Dynamic Aperture*

Dynamic aperture studies are performed with the code PATPET. Particles are tracked for 500 turns for the lattice with systematic and random multipole errors, random excitation (strength) and alignment errors. The values of multipole errors assumed are taken from similar calculations used in other projects.

Table II shows the assumed random strength and alignment errors. The alignment errors are horizontal x and vertical y displacements and rotation α about the longitudinal axis. The random errors are r.m.s. values for gaussian distributions, which are truncated at two sigmas. Tracking is done after closed orbit corrections. The result for the dynamic aperture at the middle of the long insertion straight is shown in figure 3.

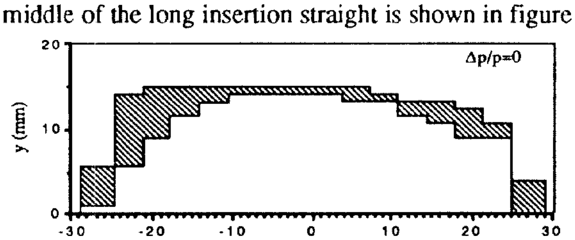

Fig. 3: Dynamic aperture for UVX2 with systematic and random multipole, strength and alignment errors for Δp/p=0.

For the closed orbit correction we use 24 monitors for both horizontal and vertical readings, 18 horizontal and 12 vertical correctors. Figure 1 gives the position of these elements in one superperiod. Ten random machines are studied for the nominal errors. In table III, we give the average and standard deviation of various parameters before and after correction. It should be emphasized that 0.2 mm r.m.s. alignment errors (gaussian truncated at two sigma) on monitors are included.

Table II : Alignment and strength random errors (one standard deviation) in magnetic elements.

$<\Delta x>$,$<\Delta y>$	0.2 mm
$<\Delta\alpha>$	0.02°
$<\Delta S/S>$	0.1 %

Table III: Closed orbit correction . Comparison between unperturbed, perturbed and corrected machines.

Parameter	Unperturbed	Perturbed	Corrected
ν_x	5.270	5.283 ± 0.010	5.271 ± 0.002
ν_y	2.169	2.173 ± 0.014	2.170 ± 0.004
$<x^2>^{1/2}$ (mm)	0.0	1.98 ± 0.92	0.19 ± 0.03
x_{max} (mm)	0.0	4.80 ± 2.23	0.55 ± 0.14
$<y^2>^{1/2}$ (mm)	0.0	4.35 ± 2.39	0.17 ± 0.03
y_{max} (mm)	0.0	9.87 ± 5.09	0.52 ± 0.11
ε_x (10^{-9} rad.m)	65.1	127.3 ± 140.7	65.2 ± 1.7
ε_y (10^{-9} rad.m)	0.0	0.87 ± 0.81	0.04 ± 0.02
$\varepsilon_y/\varepsilon_x$ (%)	0.0	0.73 ± 0.41	0.06 ± 0.03
$<\lvert\theta_x\rvert>$(mrad)	-	-	0.14 ± 0.01
$<\lvert\theta_x\rvert_{,max}>$(mrad)	-	-	0.36 ± 0.08
$<\lvert\theta_y\rvert>$(mrad)	-	-	0.11 ± 0.03
$<\lvert\theta_y\rvert_{,max}>$(mrad)	-	-	0.26 ± 0.06

* The average values for parameter z (over 10 simulations) are given in the form $<z>\pm\sigma_z$.

3. COLLECTIVE EFFECTS

In this section, we shall be concerned with the following issues: microwave instability and potential well distortion, emittance growth due to intrabeam scattering (IBS) and beam lifetime. Our aim is to perform a calculation of beam lifetime and growth rates consistent with the equilibrium beam dimensions determined by these effects. This is done with the computer code ZAP[4] for 100 MeV and 1.15 GeV assuming a 500 MHz RF system.

At the present stage, neither measurements nor calculations of the coupling impedance of the ring are available, thus we resort to the literature for typical values. We use 13Ω (value measured at Alladin[5]) and 2Ω (measured at Super-Aco[6]). For the HOM of the RF cavities, we use the data of the KEK 500 MHz cavity. The phenomenological Spear scaling law is used to get an effective impedance for short bunches. We have made calculations both with and without Spear scaling. This is indicated by the words ON and OFF.

Recent calculations of collective effects (including coupled bunch modes) using measured and computed data for the UVX2 RF cavity are described in reference [7].