Ion Clearing in The LNLS UVX-2 Soft X Ray Source

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Abstract

The ion clearing system for the LNLS 1.15 GeV electron storage ring [1,2] is composed of 54 vertical field electrodes in the straight sections and 12 horizontal field electrodes located inside the dipole vacuum chambers. The latter do not clear ions directly bu rather produce large longitudinal cross-field velocities towards the ends of the dipole where ions are removed with vertical field electrodes. Electrode geometry, position and voltage are specified acording to the variation of the beam potential well depth along the machine, the expected longitudinal ion velocity, the allowable residual neutralisation and the electron orbit perturbation due to clearing electrodes.

1. ION PRODUCTION AND BEAM NEUTRALIZATION

The circulating bunches in an electron storage ring interact with the molecules of the residual gas producing low energy ions that may, under certain circumstances, be trapped by the potential well of the beam[3]. If the ions are not cleared away (by inherent instabilities of their oscillatory motion or by external means), their accumulation leads to partial or total neutralization of the electron beam causing a shift and spread of the electron betatron frequencies, an increase of the local pressure, and transverse coherent instabilities. All these effects are deleterious to the performance of a light source, implying shorter lifetime and increased equilibrium emittance. Our purpose is to estimate the magnitude of ion-related effects in UVX-2 and to propose an ion-clearing system based on these results. The ion clearing process via static electric fields is studied with numerical tracking. The residual gas is assumed to be composed solely of molecular Hydrogen and Carbon monoxide.

The forces of the beam on trapped ions depend critically on beam size. Table 1 summarizes the relevant parameters. Transverse equilibrium bunch dimensions at full energy are assumed to be given by the natural values (i.e., no emittance growth due to intra-beam scattering (IBS) is considered, nor any increase in energy spread due to microwave instability). Although this assumption is reasonable for high energy and not too high currents[4], it breaks down at low energy. Therefore the values quoted for 100 MeV are derived from a calculation with the computer code ZAP[5] ,which takes into account bunch lengthening and widening due to the combined effects of microwave instability, potential well distortion and intrabeam scattering. The RF harmonic number is 146 and the machine circumference 87.8 m.

The rate of production of ions by electronic impact is given by

$$R = \frac{N}{\tau_n} = N\sum_i \frac{1}{\tau_i} \qquad (1)$$

where τ_n is the neutralization time,i.e., the time it takes for one electron in the beam to create one ion of any of the molecular species contained in the vacuum chamber, τ_i is the corresponding quantity for the i-th molecular species, N is the total number of electrons in the machine and the sum goes over all species. Ionization cross sections and the corresponding ionization times are shown in tables 2 and 3. Table 4 shows the ion drift velocities inside the dipoles (cross-field drift). The thermal drift velocities (straight sections) are 2 km/s for H_2 and 0.5 km/s for CO. These results are used to derive the maximum allowable distance between clearing electrodes consistent with 1 x 10^{-3} average residual neutralisation (which corresponds to a maximum tune shift - in the vertical direction - of 8.5×10^{-3}) shown in table 5. These values provide only an order of magnitude for the number of electrodes needed to clear the whole machine, given the ring circumference. In particular, the reasoning on which they are based disregards the effect of localized ion pockets. In UVX-2 one important ion pocket (about 5 V at 100 mA) occurs inside the dipoles. Local clearing is provided there (see section 3). Other pockets occur in regions where clearing electrodes cannot be installed such as injection kickers. Ions trapped in those regions will have to be dealt with by other means such as the missing bunch scheme (see section 2) or beam shaking.

Table 1 : UVX-2 Machine parameters

Parameter	Injection (100 MeV)	Full Energy (1.15 GeV)	Unit
emittance	52.0	6.34	x 10^{-8} π m rad
energy spread	0.15	0.059	%
coupling	10%	1%	

Table 2 : Ionization Cross Sections

Cross-Sections (10^{-22} m^2)	Injection (100 MeV)	Full Energy (1.15 GeV)
Hydrogen	0.28	0.34
Carbon Monoxide	1.33	1.66

Table 3: Ionization times

	Partial Pressure (ntorr)	Density 10^6cm^{-3}	τ_i - 100 MeV (sec)	τ_i - 1.15 GeV (sec)
H_2	0.7	22.5	5.4	4.4
CO	0.3	9.6	2.6	2.1
Total	1.0	32.1	1.8	1.4

Table 4 Cross field drift velocities for I = 100 mA for ions created at the edge of the beam. Beam dimensions are average value inside the bending magnets.

Energy (MeV)	σ_x (μm)	σ_y(μm)	V_D H_2(km/s)	V_D CO(km/s)	B_0 (T)
100	760	851	3.88	0.31	0.122
1150	278	99.6	7.06	1.19	1.4

Table 5: Maximum allowable interelectrode separation consistent with 1 x 10^{-3} residual neutralization and 100% efficient ion capture at electrodes.

Molecules	100 MeV		1.15 GeV	
	L_{ther} (m)	$L_{cross\text{-}field}$ (m)	L_{ther} (m)	$L_{cross\text{-}field}$ (m)
H_2^+	6.8	13.6	5.4	20
CO^+	1.8	1.1	1.5	3.2

2. Beam Fields, Trapping Conditions and Clearing Requirements

The beam self-field for an elliptical homogeneous coasting beam is given by :

$$E_{x,y} = \frac{I}{2\pi\varepsilon_0 c} \frac{[x,y]}{\sigma_{x,y}(\sigma_x + \sigma_y)} \tag{2}$$

where I is the average beam current.
Figure 1 shows this linear beam self-field along the machine.

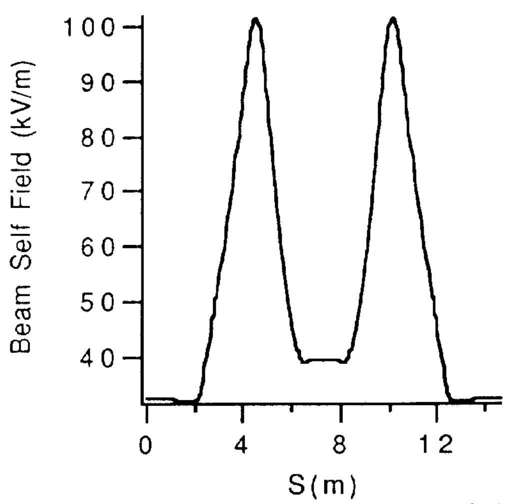

Figure 1: Beam self-field along one superperiod of the UVX-2 machine at 1.15 GeV. The fields are calculated in the homogeneous beam approximation. Beam current is 400 mA. At 100 MeV, beam fields are 3 to 4 times smaller but follow the same curve.

Trapping of ions is described in linear approximation by the critical mass above which ions are stable in the beam's potential well. For UVX-2, all ions are stable at 1.15 GeV and 100 MeV if all buckets are filled with nominal current (100 mA). The critical mass criterium applies to a homogeneously filled machine, i.e., to a series of equally spaced and equally intense electron bunches. The introduction of a gap in the bunch train creates a number of stable and unstable mass bands, thus providing an important clearing mechanism. Just as in the homogenuous bunch filling case, ion stability may be determined by calculating the trace of the transfer matrix for the passage of all buckets (either filled or not) through a given azimuthal position. Figure 2 shows the result of one such calculation where a gap of 46 empty buckets is introduced.

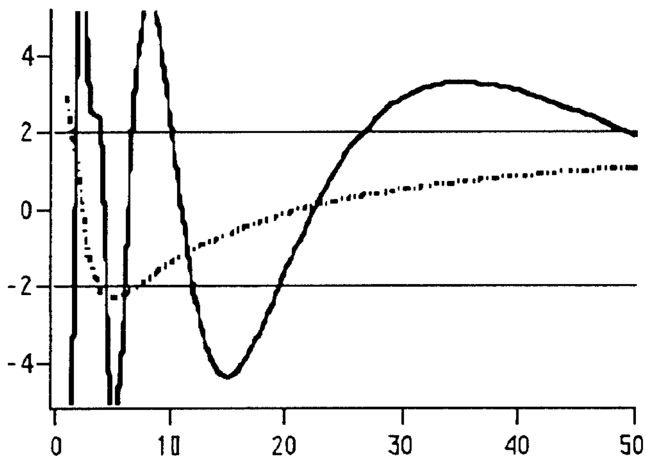

Figure 2 : Trace of the transfer matrix for a complete period at 1.15 GeV as a function of th ion mass number. 100 buckets filled, 46 buckets empty. Full curve - 300 mA, dotted curve - 10 mA. Note the stable and unstable bands. These results apply to the point of minimum critical mass in the ring (σ_x = 838μm, σ_y = 102 μm).

The beam self-field (2) is used as an estimate of the necessary clearing field. Ion motion under the action of the repetitive bunch kicks (calculated for a bigaussian transverse electron distribution) and a homogeneous static clearing field confirms that ions are safely cleared in a few microseconds after ion creation. Figure 3 shows one such calculation for the case of a carbon dioxide ion (A=44). Thus, 20 cm long electrodes are capable of clearing an ion of up to about 100 km/s longitudinal velocity. This is far above the expected longitudinal velocities in UVX-2, either thermal (2 km/s) or cross-field drift velocities in the bending magnets (7 km/s).

Due to the large number of electrodes, distortion of the electron beam's closed orbit may be significant. In fact, if all electrodes (except those in the dipoles) are positioned such that the clearing field in all of them points in the same direction, the vertical closed orbit deviation may be as large as 0.8 mm. In order to reduce that effect, straight section electrodes are positioned in alternating sides of the vacuum chamber. By alternating the field direction along the machine, the maximum closed orbit deviation may be brought down to 0.2 mm.

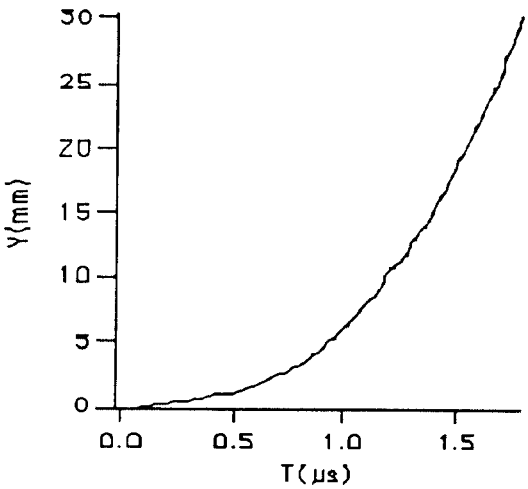

Figure 3: CO_2 ion trajectory in a straight section. A vertical clearing field of 150 V/cm is applied (this is the value given by (2) at a point in the machine where σ_x=650μm and σ_y=130μ m). Bunch kicks are calculated for a gaussian electron charge distribution and a homogeneous bunch filling is assumed. I=200 mA.

3. Clearing Electrodes

Straight section clearing electrodes are cylindrical striplines match terminated at both ends to reduce their beam coupling impedance. Voltages vary from 2 to 5 kV. Figure 4 shows the field profile as calculated with the code POISSON[6]. As noted above, an important ion pocket in UVX-2 is located inside the dipole vacuum chamber (where the horizontal β function is made small to minimize the emittance). In order not to reduce the available verticle aperture , vertical electrodes (i.e., electrodes producing a horizontal electric field) are chosen in the dipoles, which provide sufficient cross field drift velocities (4 km/s for CO) for the ions to get out of the dipole where they can be cleared with conventional electrodes. The electrode is made up of two rectangular plates 5mm in width, 20 mm apart and provides up to 500 V/cm clearing field.

Figure 5 shows the overall lay-out of the clearing system in one superperiod of UVX-2.

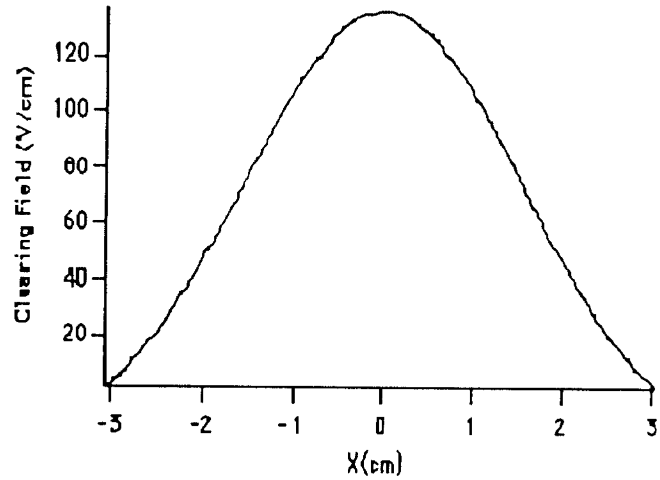

Figure 4: Vertical field profile of the straight section clearing electrodes (cylindrical striplines in a circular vacuum chamber) for 1 kV electrode voltage.as given by POISSON.

4. References

[1] L.Lin, L.Jahnel, P.Tavares, *The LNLS UVX-2 Soft X-Ray Source*, These Proceedings.

[2] P.Tavares, *Ion Trapping in The UVX-2 Storage Ring*, LNLS Report (1991)

[3] Y.Baconnier, *Neutralization of Accelerator Beams by Ionization of The Residual Gas*, CAS School 1984.

[4] The threshold for microwave instability at 1.15 GeV and 13 Ω broaband impedance (with Spear scaling) is about 5 mA per bunch.

[5] M.S.Zisman, S.Chattopadhyay, J. Bisognano, *ZAP User's Manual*. LBL Report LBL 21270 (1986).

[6] Los Alamos Accelerator Code Group, *Reference Manual for Poisson*, LA-87-UR-87-126.

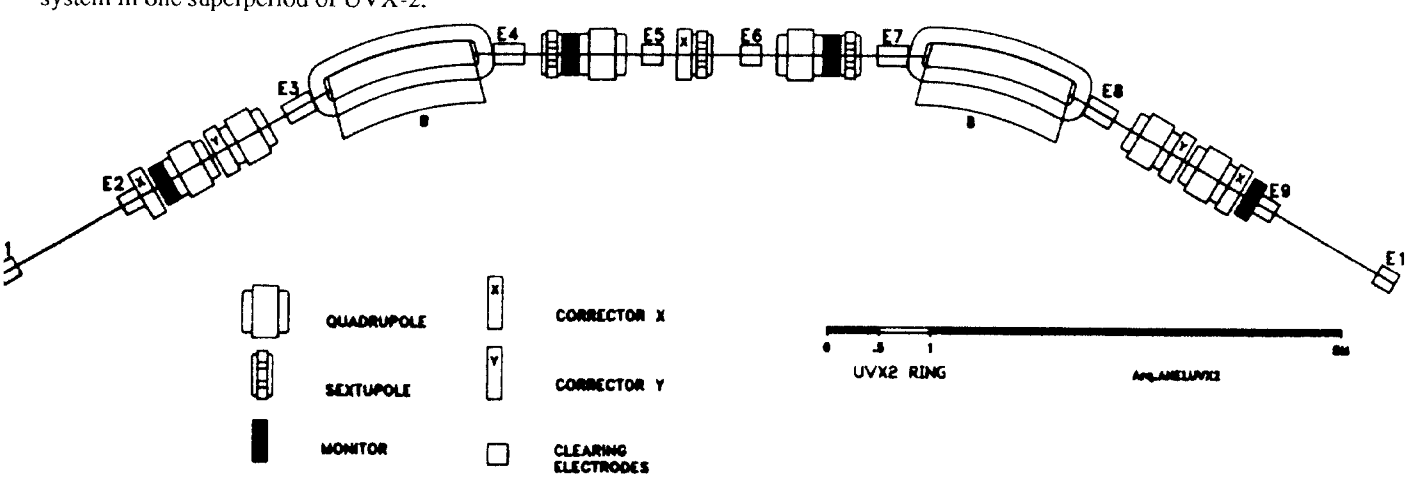

Figure 5 :Lay-out of the UVX-2 clearing system.