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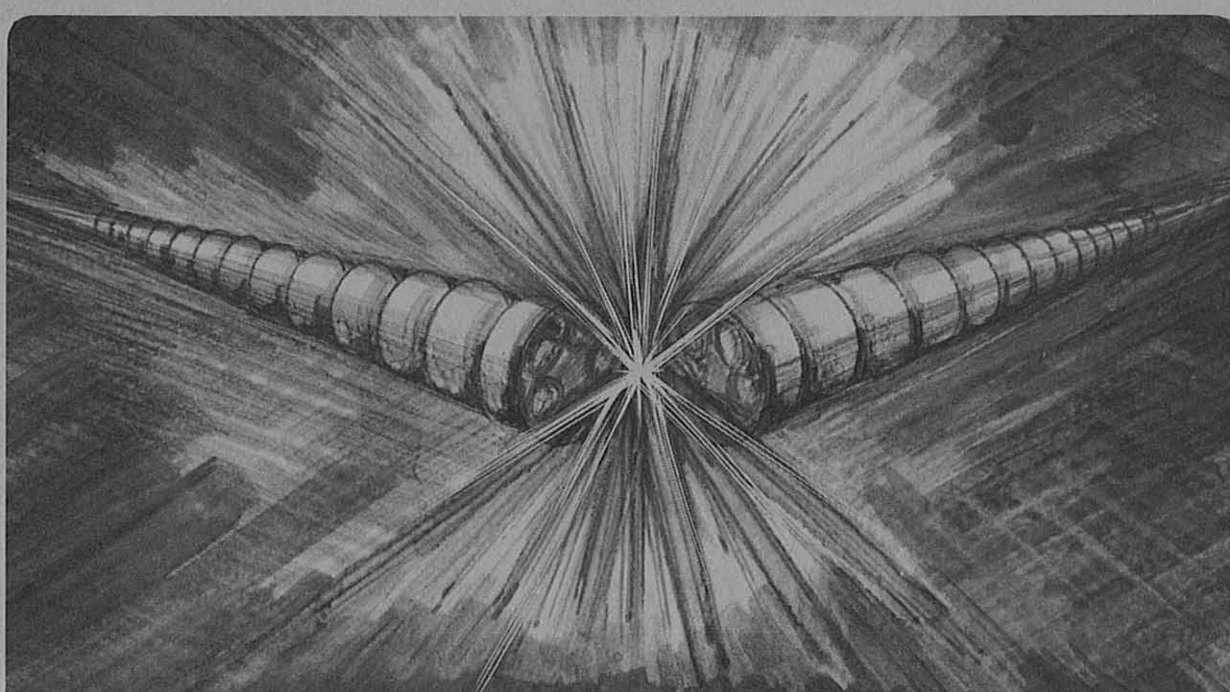

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Abstract

The LBL Advanced Light Source (ALS) will be a third generation synchrotron radiation facility. It is based on a low emittance 1-2 GeV electron storage ring (natural radial emittance < 10 nm-rad), optimized to produce extremely bright beams of electromagnetic radiation (in the energy range from a few eV to around one keV) from insertion devices known as undulators. The storage ring is fed from an injection system consisting of a 50 MeV linac and a 1.5 GeV, 1 Hz, booster synchrotron, which can fill the ring to its nominal operating current (400 mA, multibunch, or 7.6 mA, single bunch) in a few minutes. As well as high brightness (which is a consequence of the very small electron beam emittance in the storage ring), the design emphasizes: picosecond time structure, laserlike coherence properties, narrow bandwidth, and long beam lifetimes. The more familiar continuous synchrotron radiation spectrum will be available from bending magnets and from wiggler magnets. This paper gives a general description of the ALS and discusses some of the significant design issues associated with the low emittance storage ring that is required for this new facility.

Introduction

The Lawrence Berkeley Laboratory (LBL) is presently constructing a third generation synchrotron radiation source known as the Advanced Light Source (ALS). The facility, scheduled to come into operation in 1992, is based on a low emittance electron storage ring with 12 long straight sections. One of the straights is used for injection elements and a second is partially occupied by two rf cavities, leaving ten straights free for insertion devices up to 5 m in length. In addition to radiation from the insertion devices, there will be provision for up to 48 bending magnet beam ports. Features emphasized in the design of the ALS include low electron beam emittance, picosecond time structure, long beam lifetimes and synchrotron radiation with very high brightness, narrow bandwidth and laserlike coherence properties.

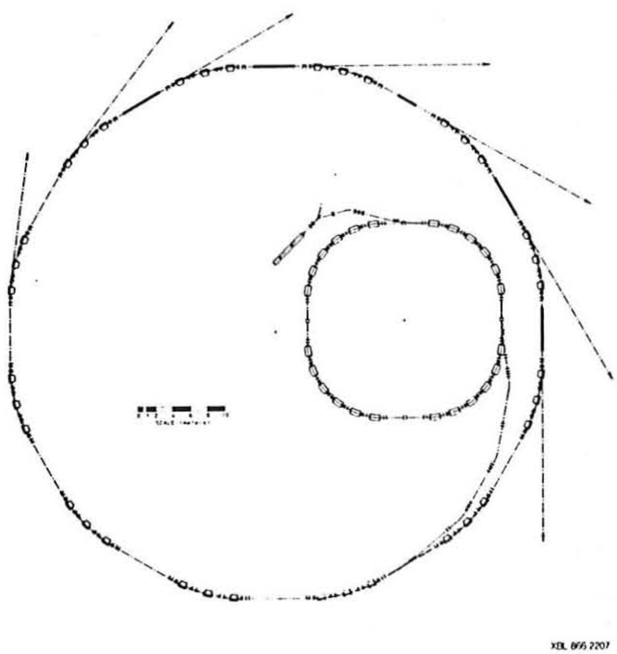

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Fig. 1. Overall layout of storage ring and injection system.

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General Description of the ALS

The accelerator systems of the ALS comprise a 50 MeV linac; a 1 Hz, 1.5 GeV booster synchrotron; and a storage ring optimized for operation at 1.5 GeV, but capable of operation in the range 1.0 - 1.9 GeV. Figure 1 shows the layout of the accelerator components and Table 1 lists the major parameters of the storage ring. A description of the many subsystems of the ALS can be found in Ref. 1.

Table 1 Summary of Major Storage Ring Parameters[a]

Nominal energy (GeV)	1.5
Maximum circulating current, multibunch (mA)	400
Maximum circulating current, single bunch (mA)	7.6
Natural horizontal emittance (m-rad)[b]	4.08×10^{-9}
Bunch length (ps), (2σ), at maximum current	
Multibunch (ps)	28
Single bunch (ps)	47
Peak Energy (GeV)	1.9
Beam lifetime, half-time	
Gas scattering[c] (hr)	10.5
Touschek, maximum current	
Multibunch (hr)	18.5
Single bunch (hr)	8.4
Filing time	
Multibunch, to 400 mA (min)	2.1
Single bunch, to 7.6 mA per bunch (s)	16
Circumference (m)	196.8
Orbital period (ns)	656.4
Harmonic number	328
Radio frequency (MHz)	499.654
Peak effective rf voltage (MV)	1.5
Number of superperiods	12
Insertion straight section length (m)	6.75
Length available for insertion device (m)	5.0
Bending filed (T)	1.248
Injection energy (GeV)	1.5
Betatron tunes	
Horizontal	14.28
Vertical	8.18
Synchrotron tune	0.0082
Natural chromaticities	
Horizontal	-24.1
Vertical	-28.5
Beta functions at insertion symmetry points	
Horizontal (m)	11.0
Vertical (m)	4.0
Momentum compaction	1.43×10^{-3}
Damping times	
Horizontal (ms)	13.1
Vertical (ms)	17.6
Longitudinal (ms)	10.7
Number of sextupole families	2

[a]All parameters at nominal energy unless otherwise noted.
[b]Defined as $\varepsilon = \sigma^2/\beta$, where σ is the rms beam size and β the amplitude function.
[c]10-mm vertical gap, 1 n Torr N_2.

The Storage Ring Magnet Lattice

The magnet lattice of the ALS storage ring is based on the triple bend achromat (TBA) structure. Figure 2 shows one unit cell (one-twelfth) of the machine and Fig.3 shows the amplitude and dispersion functions through the cell. A novel feature of this lattice structure is the use of a vertically focusing gradient in the bending magnets. This gradient performs two functions: firstly it controls the amplitude of the vertical betatron function, which has its maximum value in the bend magnets; and secondly it produces an increase in the radial damping partition number, leading to a reduction in the natural emittance of the lattice. A more complete discussion of the properties of the TBA lattice can be found in Refs. 1 and 2. As with all low emittance storage rings, the single particle dynamics in the storage ring are dominated by the strong sextupoles that are required for chromaticity compensation. However, in contrast to other low emittance lattice structures, the performance of the TBA (in terms of dynamic aperture, and amplitude and momentum dependent tune variations) is quite adequate when only two families of sextupoles are employed.

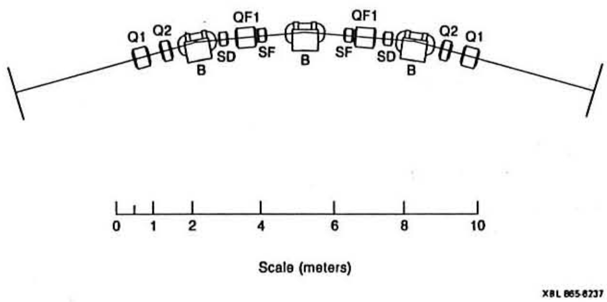

Fig. 2. One unit cell of the TBA structure.

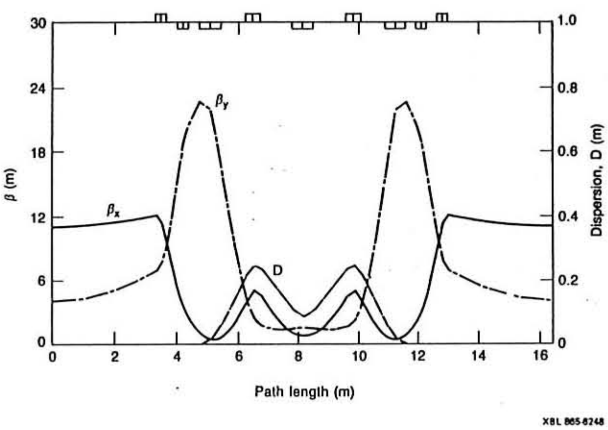

Fig. 3. Lattice functions through one unit cell of the TBA structure.

Collective Effects and Beam Lifetime

Two typical operational scenarios are envisaged for the ALS: multibunch mode and single (or few) bunch mode. In terms of collective effects the more stringent configuration is the single bunch mode, where we specify an average current of 7.6 mA with an emittance of less than 10 nm-rad and an rms bunch length of less than 25 ps. At these electron densities, collective effects can play a significant role. The consequences are felt in bunch lengthening (due to the microwave instability), in transverse emittance growth (due to intra-beam scattering) and in beam lifetime (due to Touschek scattering). A major factor in determining the magnitude of these effects is the broadband impedance of the vacuum system, i.e., the vacuum chamber itself, diagnostic devices, bellows, etc., and the equivalent broadband impedance arising from the many rf cavity higher-order modes. Calculations based on modeling the rf cavity modes yield an estimate for Z/n of 0.25 ohms per cavity and we expect the remainder of the system to contribute less than 2 ohms [3]. (Note that these estimates are consistent with those measured at other "modern" rings, for example, Super-ACO measures a total ring impedance, with one cavity, of Z/n = 2 ohm [4].) These estimates have been used in the code ZAP [5] to predict the performance of the ALS. A full description of the results is given in Ref. 6 from which we extract Fig. 4, the expected bunch lengthening at the nominal energy of 1.5 GeV. Calculations of the relevant collective effects indicate that the performance goals (short bunch length, long lifetime and small transverse emittance), are achievable.

In the multibunch mode we will fill a string of about 250 (out of 328) contiguous rf buckets, up to a total average current of 400 mA. The gap in the train of pulses is left in order to prevent ion trapping [1]. With less than 2 mA per bunch we do not expect any significant deterioration in the performance of the light source due to the microwave instability, Touschek scattering or intrabeam scattering. There will, however, be a need for higher order mode suppression and feedback systems to stabilize motions due to multibunch instabilities that couple mainly through the higher-order modes in the rf cavities.

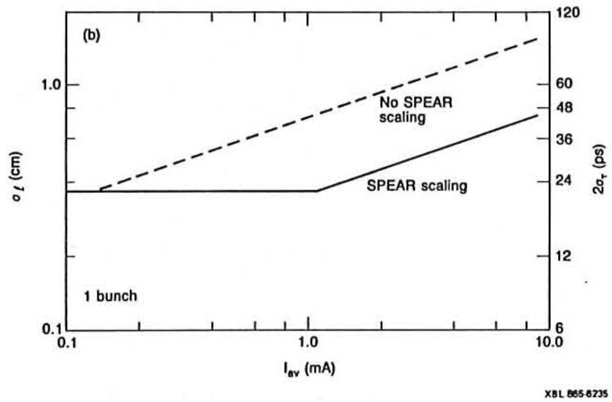

Fig. 4. Bunch length vs. current at 1.5 GeV, with and without the SPEAR scaling law.

Influence of Magnet Imperfections, Misalignments and Insertion Devices

Studies have been carried out to investigate the sensitivity of the ALS, particularly in terms of the dynamic aperture, to systematic and random magnetic field errors, to closed orbit distortion (COD), and to the effects of insertion devices. Much of this work is reported in Refs. 1 and 7. The most significant deterioration in performance arising from magnet imperfections comes from the random gradient errors in the quadrupoles and gradient bend magnets. Relative errors of 1×10^{-3} rms result in the reduction in aperture shown in Fig. 5. This effect is due mainly to the disruption of the regular phase advance between the very strong lattice sextupoles. Since we will measure all production magnets, it will be possible to shunt all the bend magnets to ensure sufficient repeatability, and to pedigree the quadrupoles into sets that will minimize the phase distortion.

Closed-orbit distortions are generated by magnet placement errors, bend magnet field errors and bend magnet tilt errors. We have developed algorithms to minimize the COD using a combination of the most effective corrector method and the local bump method. The orbit is sampled at 96 monitor stations around the circumference with correction applied via 72 correctors in the horizontal plane, and 48 in the vertical plane. A typical result for the harmonic content of the horizontal COD as the correction scheme is applied is shown in Fig.6. It can be seen that the orbit progresses from a distribution dominated by harmonics close to the horizontal betatron tune (nu-x = 14.28) to one which is truly random. We find that the degree of correction is limited to the accuracy with which we can measure the orbit, assumed here to be 0.1 mm rms. Typically, the correction algorithm produces corrected closed orbits of 0.08 mm rms in both planes.

The ALS will be the first machine of its kind to have a large fraction of its circumference (more than one-quarter) occupied by insertion devices. These devices are intrinsically nonlinear and also produce focusing in one or both transverse planes. The main parameters of one such device, known as U9.0 (U for "undulator", 9.0 for the period length in cm), are given in Table 2. The principal effect of U9.0 is to change the vertical betatron tune, by as much as 0.042 when the device is fully closed. This, like the random focusing errors, causes a phase shift between the sextupoles and results in a reduction of the dynamic aperture. Studies are currently under way to determine the relative effects of the linear and nonlinear components of the insertion device fields (for example, the change in dynamic behavior when the nonlinear components of U9.0 are artificially turned off), and to find compensation schemes to minimize their effects.

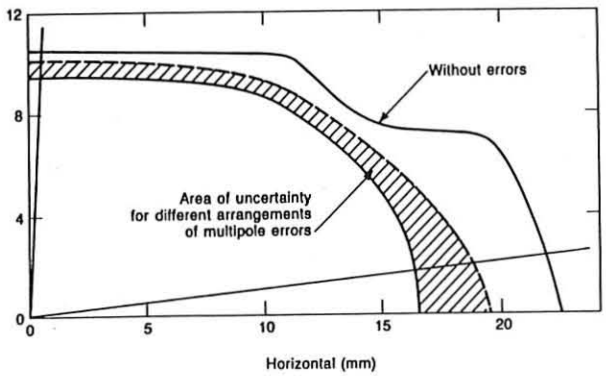

Fig. 5. Dynamic aperture in the presence of multipole errors.

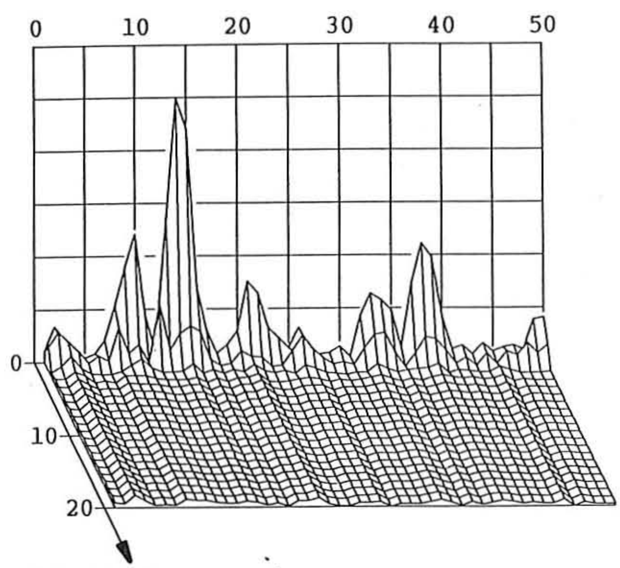

Fig. 6. Harmonic distribution of horizontal COD.

Table 2 Main Parameters of Undulator U9.0

Length [m]	4.8
Undulator period [cm]	9.0
Number of periods	53
Maximum peak field [T]	1.15
Gap [mm]	20.90
Maximum K-value	9.64

Beam Positional and Angular Stability

An important requirement of the users of the synchrotron radiation is the position and angular stability of the photon beam. If we assume a gaussian beam distribution, centered on the entrance slit of a monochromator with well matched optics, the throughput will vary by 1% for a relative beam motion of 17% of its rms size. In the vertical plane this corresponds to absolute beam motion of about 6 microns. In order to meet this stability requirement, careful attention must be given to minimizing all local sources of vibration, for example, in pulsing power supplies and rotating machinery, and, where necessary, such equipment must be mounted on isolation plinths. Despite all such care, we anticipate that active feedback will be necessary to meet the required tolerances. To this end steering magnets, capable of providing local correction of both position and angular deflections, in both the horizontal and vertical planes, are provided in each long straight section. Tests on a model steering magnet, mounted around the aluminum vacuum vessel, indicate that their response, limited by eddy current effects, will be adequate for correction up to 100 Hz in the (more sensitive) vertical plane, but restricted to about 10 Hz in the horizontal plane. A study of the coupling and stability of up to eleven feedback systems is currently under investigation. As well as these high-frequency stability issues, we must also be concerned about longer term (for example, diurnal) drifts. Again, as much as possible must be designed into the fabric of the facility to minimize such motions (for example, by controlling temperature gradients across structures), but it is inevitable, in this case, that active feedback will be required.

Summary

In this paper we have described the main features of the Advanced Light Source now under construction at LBL. The design is well optimized, well within the capabilities of current technologies, and sufficiently flexible to meet the demands of a next generation synchrotron radiation source. There are many challenges associated with this particular class of accelerator, some of which we have addressed in this paper. We look forward to solving them on the "real" machine.

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