THE MAGNET LATTICE OF THE LBL 1-2 GeV SYNCHROTRON RADIATION SOURCE*

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Abstract

This paper describes the magnet lattice chosen for the LBL 1-2 GeV Synchrotron Radiation Source. The structure has a circumference of 196.8 m, with 12 dispersion free straight sections that can accommodate insertion devices up to 5 m long. The achromatic arcs that connect these straight sections feature combined function (gradient) bending magnets. Utilization of three such magnets in the so-called three-bend-achromat (TBA) arrangement, has several beneficial effects: (1) it reduces the amplitude of the vertical beta-function in the bending magnets, thereby minimizing the required aperture; (2) it changes the damping partition number in such a way as to reduce the natural emittance; and (3) it produces separation of the beta-functions such that relatively low sextupole strengths are sufficient for chromatic correction. The result is a structure with very low emittance (4 nm-rad at 1.5 GeV) that is correctable with only two families of sextupoles while maintaining excellent chromatic properties and acceptable dynamic aperture.

Introduction

The LBL 1-2 GeV Synchrotron Radiation Source is a third generation, low emittance storage ring optimized to produce high brightness XUV and soft X-radiation from long undulator and wiggler magnets. Construction of the Source will start in 1988, with full operation (including five insertion devices) expected by the end of 1992. The facility is based on an electron storage ring (circumference 196.8 m) with 12 dispersion free straight sections, 11 for insertion devices and 1 for injection, connected by achromatic arcs. Each achromat contains three gradient bending magnets in the arrangement first suggested by Vignola for a 6 GeV light source [1]. This structure has come to be known as the three-bend-achromat, or TBA, lattice.

In this paper we describe the details of the storage ring and discuss the characteristic features of the lattice. An overview of the Source, the injection system and a discussion of the effects of field errors and insertion devices can be found in three companion papers presented at this Conference [2,3,4].

Lattice Description

Fig. 1 shows one of twelve identical unit cells that make up the magnet lattice of the LBL Light Source. Table 1 describes the parameters of the individual components. The long dispersion-free straight sections are matched into the archromatic arcs by the quadrupole doublets labelled Q1/Q2, and the dispersion in the arc is controlled through the quadrupoles labelled QF1. Vertical focusing within the achromat is achieved by including a gradient in the three bending magnets. Not only does this approach limit the vertical beta function within the magnets (and so reduces the aperture requirements), but it also changes the damping partition numbers in such a way as to reduce the natural emittance, and, as we can see in Fig. 2, produces beneficial separation of the beta functions at the positions of the chromatic sextupoles, thus reducing the fields required for correction. The dimensions of the cell have been carefully optimized to produce the required betatron tunes and beta values at the center of the insertion straight, labelled β*. Once these dimensions are fixed, these two sets of variables are no longer independent, i.e., the values of the beta-functions in the insertion region determine the tune of the machine. This dependency can be overcome by using another family of quadrupoles in the achromat and space has been reserved in the lattice should the need for such flexibility be found to be necessary. Fig. 2 shows the usual lattice parameters for the nominal tune of $\nu_x = 14.28$, $\nu_y = 8.18$, and Table 2 contains a summary of the more important lattice parameters. At the nominal energy of 1.5 GeV this lattice gives a beam with a natural emittance of 4.1 nm-rad.

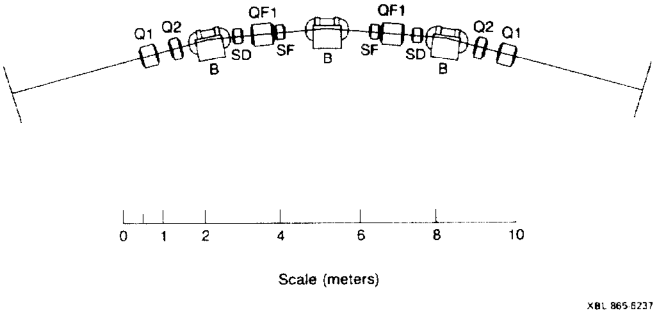

Fig. 1 One unit cell of the TBA structure.

A more detailed description of how the TBA lattice is optimized can be found in Ref. 5.

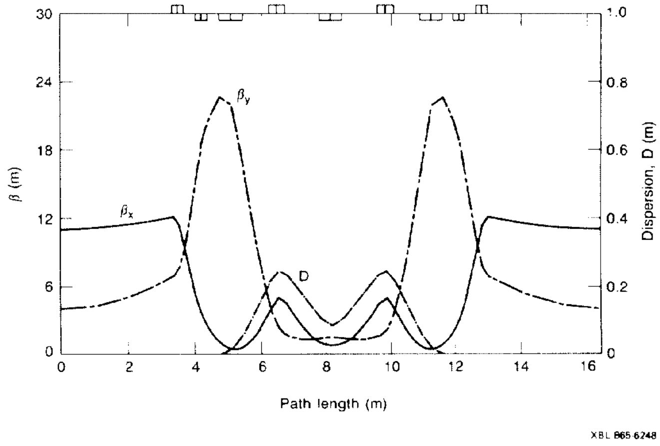

Fig. 2 Lattice functions through one unit cell of the TBA structure.

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Table 1. Structure of LBL Light Source Unit Cell

Component	Length (m)	Strength
Sym-Q1	3.375	
Q1	0.35	$+2.212\ \mathrm{m}^{-2}$
Q1-Q2	0.425	
Q2	0.2	$-2.193\ \mathrm{m}^{-2}$
Q2-B	0.425	
B	0.7	1.248 T, n = -16.088
B-SD	0.3	
SD	0.2	$-88.1\ \mathrm{m}^{-3}$
SD-QF1	0.3	
QF1	0.5	$+2.589\ \mathrm{m}^{-2}$
QF1-SF	0.1	
SF	0.2	$+115.6\ \mathrm{m}^{-3}$
SF-B	0.775	
B(1/2)	0.35	1.248 T, n = -16.088
Half Cell	8.2	
Circumference	196.8	

Table 2. Summary of Storage Ring Parameters

Nominal energy [GeV]	1.5
Peak energy [GeV]	1.9
Injection energy [GeV]	1.5
Circumference [m]	196.8
RF frequency [MHz]	499.654
Harmonic number	328
Natural emittance (1.5 GeV) [nm-rad]	4.08
Momentum compaction	0.00143
Betatron tunes - radial	14.28
- vertical	8.18

Tunability

In any storage ring it is important to be able to move the tune of the machine to avoid resonances and instabilities. The gross tunes of the LBL Light Source have been chosen specifically to be as far as possible from systematic third-order resonances that are driven by the strong sextupole fields required for chromatic correction. This restricts the tuning range of interest to $14.0 < \nu_x < 14.5$, $8.0 < \nu_y < 8.5$. Since the quadrupoles QFA are used to match the dispersion in the arcs, only quadrupoles QF and QD are available for tuning. This limits the number of independently variable parameters to two, say ν_x and ν_y, leaving the associated parameters such as emittance, β_x^* and β_y^* to float. However, we find that within the tune range of interest these variations are acceptable. For example, over the whole of the required half-integer tune square the emittance changes by only 4%, β_x from 10.0 m to 13.0 m, and β_y from 3.5 m to 4.5 m. We do not expect that changes of these magnitudes will have any serious impact on the operation of the Source.

Chromaticity Correction and Dynamic Aperture

The natural chromaticity (defined as $\xi_{x,y} = \Delta\nu_{x,y}/\delta$) of lattices designed for low emittance beams are usually quite high and the Light Source is no exception: $\xi_x = -24$, $\xi_y = -29$. In order to combat an effect called the head-tail instability, and also to limit the tune spread at injection when the energy spread can be large, it is necessary to adjust the chromaticities to zero or to a small positive value. We have found that correction can be achieved with only two families (the minimum number required to ensure correction in both transverse planes) whilst maintaining adequate chromatic behavior. Fig. 3 shows the momentum dependent tune-shift of the structure when the chromaticities are set to zero. (The energy acceptance of the Source at 1.5 GeV is in fact limited to ±3.5% by the installed rf capability, which provides 1.5 MV of accelerating voltage.)

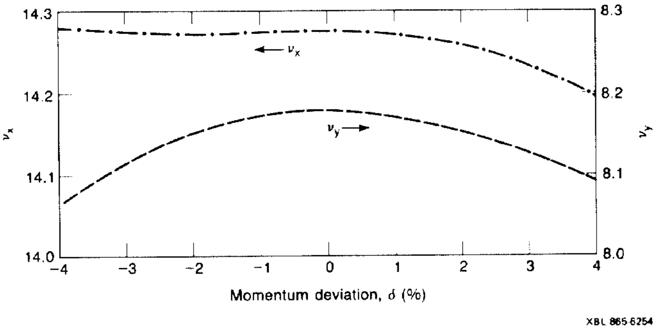

Fig. 3 Momentum-dependent tune shifts.

The problem with turning on sextupoles to correct the chromaticities is that they induce nonlinear motion into the electron trajectories, resulting in amplitude dependent tune variation and, ultimately, in unstable motion at an amplitude that defines the "dynamic aperture." We determine the dynamic aperture by tracking test electron trajectories through a computer model of the lattice (using MARYLIE [6]) and observe where the motion becomes unbounded. The result is shown in Fig. 4. Fig. 5 shows the radial phase space trajectories of two electrons, one with an amplitude well within the dynamic aperture, and the other close to instability. The distortion of the trajectories from their linear elliptical shape, caused by the sextupole fields, is clear. Variation of tune with betatron amplitude, which has particular relevance to the efficiency of the injection process, is shown in Fig. 6. We conclude that the effects introduced by chromatic correction are acceptable. The dynamic aperture, shown in Fig. 4, has been used to define the beam-stay-clear region of the storage ring, and in turn to specify the magnet apertures.

Momentum Acceptance

Another important consideration in low emittance storage rings, where the electron density within the bunch can be very high, is lifetime constraint due to Touschek scattering. In order to calculate the Touschek lifetime it is necessary to find the momentum acceptance of the machine. This

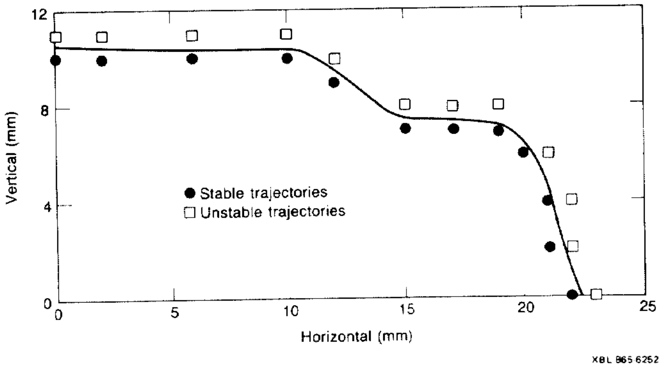

Fig. 4 Dynamic aperture of the TBA structure.

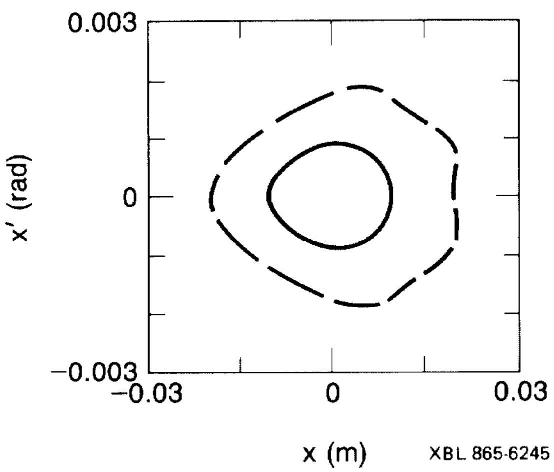

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Fig. 5 Radial phase-space trajectories of electrons with apmlitudes well within the stability limit (solid line) and close to the stability limit (dashed line).

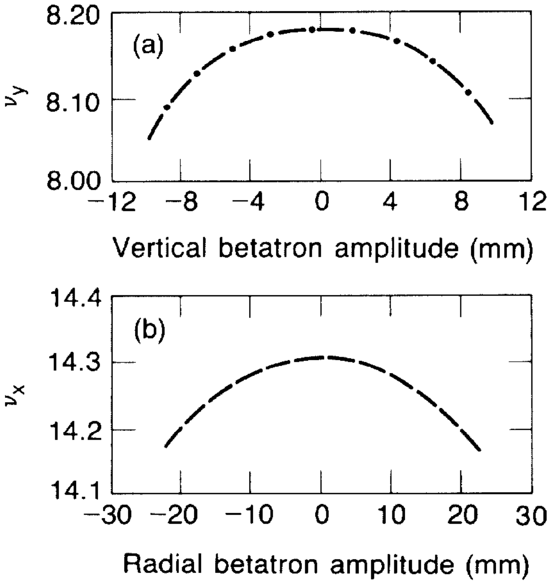

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Fig. 6 Betatron-amplitude-dependent tune shifts: (a) vertical and (b) radial.

limit can be longitudinal, given by the momentum acceptance of the rf accelerating system, or transverse, given by either the off-momentum closed orbit hitting the physical aperture, or the off-momentum trajectory going unstable. The latter limits have been found by tracking trajectories whose starting conditions simulate the most likely Touschek scatter events, i.e., they are started on axis (where the electron density is greatest) with the momentum deviation given by the scatter. The limits found in this way are $\delta = 4\%$ in the achromatic arcs (where a Touschek scatter is accompanied by a betatron oscillation) and $\delta = 5\%$ if the scatter occurs in the dispersion-free straight sections. These limits are larger than that imposed by the rf system, which gives $\Delta E/E \sim 3.5\%$ at 1.5 GeV. However, the transverse limits take over at energies below 1.2 GeV. The implications of these results on beam lifetime are discussed in a companion paper at this Conference [7].

Summary

In this paper we have described the details of the magnet lattice of the LBL 1-2 GeV Synchrotron Radiation Source. We have shown that the lattice is sufficiently flexible to permit adequate tuning and that the problems introduced by the chromatic sextupoles are acceptable.

References

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