LATTICE STUDIES FOR A HIGH-BRIGHTNESS LIGHT SOURCE

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Abstract

A number of lattices have been studied for use in a high-brightness Canadian synchrotron light source. In particular we have investigated some designs similar to the proposed 1.5 - 2.1 GeV Swiss Light Source, which incorporates superconducting dipoles in multi-bend achromats, but providing 8 or 10 rather than the original 6 straight sections. Similar emittances to those of the original (1.6 nm-rad at 1.5 GeV) can be obtained, but to achieve similar dynamic apertures great care has to be taken in placing the chromaticity- and resonance-correcting sextupoles, because of their unusual strength. A scheme is described which allows the dynamic apertures to be more than doubled to ∼100 mm-mrad in both planes.

I. INTRODUCTION

A number of lattices have been studied for use in a very-high-brightness Canadian synchrotron light source. In particular we have investigated, in collaboration with PSI, some designs with similar structures to the proposed 1.5 - 2.1 GeV Swiss Light Source, but with 8 or 10, rather than the original 6, straight sections. The SLS has a number of features superior to, or not available on, existing machines:

- a factor 2 better emittance and brightness,
- superconducting dipoles to provide hard x rays,
- two very long straight sections for advanced i.d.'s,
- a flexible lattice allowing several operating modes,
- individual tuning capability to match each i.d.

The SLS proposal uses a hexagonal lattice with four short (7 m) and two long (19 m) straight sections; there are seven focusing cells per arc tuned to provide an extremely low emittance (1.4 nm-rad at 1.5 GeV). The new lattices use the same basic cell in order to obtain the same low emittance, but fewer cells per arc (4, 5 or 6), allowing the number of arcs and straight sections available for insertion devices to be increased for only a small rise in ring circumference.

In very-low-emittance lattices the region of stable transverse motion is limited by nonlinearities introduced by the rather strong sextupoles needed for chromatic correction. This also makes it difficult to obtain the necessary dynamicacceptance independent of the machine working point. These difficulties increase for the new lattices because there is less flexibility with fewer cells per arc and because the lattice functions are in some cases asymmetric - with alternating high and low beta functions in the straight sections.

Efforts have therefore been focused on correcting the sextupole-driven resonances and finding better sextupole configurations. The algorithm used is based on simultaneous minimization of linear chromaticities and third- and fourth-order resonance strengths with the code COSY∞ [5]. The solutions obtained for the original hexagon lattice are very similar to those found at PSI.

Two approaches have been taken, as detailed in the following sections. In the first, the phase advance per cell was set solely to obtain low emittance, as in the original SLS design. One decagon and two octagon lattices of this kind were considered. The best dynamic acceptance (∼40 mm-mrad in both planes) was found for a periodicity-4 octagon with four long and four short straight sections.

The second approach was to apply the achromat concept to the chromatic corrections. With an appropriate phase advance per cell and the correct distribution of several families of sextupoles, the second-order geometric aberrations can be made vanishingly low or zero. This results in rather high dynamic acceptance, in some cases exceeding the physical aperture of the vacuum chamber. On the other hand, the tuneability of these lattices is more limited.

Lattice Structure

As for the SLS hexagon, each repeat section is an N-bend achromat (NBA) consisting of N-2 bending cells ("C cells" with $\theta \simeq 10°$) with a half-bend dispersion suppressor and a half-straight (together forming an "H section") on each side. Figure 1 illustrates this basic structure for a 5-bend achromat consisting of three C cells and two H sections. The F and D quadrupoles in each cell form independent families.

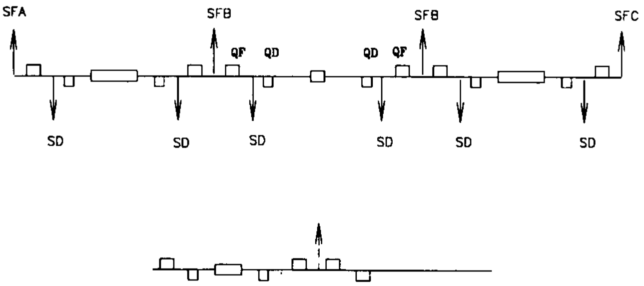

Figure. 1. Lattice elements: (above) 3 C cells with a central superconducting dipole; (below) H section composed of dispersion suppressor and half straight.

II. HIGHER-PERIODICITY LATTICES SIMILAR TO SLS

The distinguishing feature of these lattices is that resonance correcting sextupoles are installed both in dispersive (C cell) and nondispersive (H section) locations.

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The octagon lattice OCT4, composed of 4 superperiods of a 45°arc and its mirror image, has been considered both at TRIUMF and PSI[3]. Each arc consists of three C cells with 11° dipoles and one long and one short H section with 6° dipoles. The highest transverse and longitudinal dynamic apertures (units μm.rad, %) so far obtained are hor./vert./energy = 65/35/±4% and 45/41/±1%, corresponding to natural emittances of 4.7 nm.rad and 2.7 nm.rad respectively at 1.5 GeV. (Although these rings are designed to run up to 2.1 GeV, we quote emittances at the lower energy throughout, to facilitate comparison with existing machines.)

In the decagon lattice DEC288 each 180° superperiod consists of three 5BA 40° arcs and two 4BA 30° arcs. The performance achieved so far is inferior to that of SLS (see Table 1).

III. SECOND-ORDER ACHROMAT LATTICES

To implement the second-order achromat principle groups of cells are created with integer-π total phase advance. This ensures that a sextupole is always paired with a member of the same family exactly in antiphase, thereby canceling some of the driving terms of third-order betatron resonances in a ªselfcompensatingº scheme . In the lattices discussed here, this is achieved for the focusing sextupoles by making the horizontal tune advance by an integer fraction $n/2m$ (n odd) in each C cell, so a sequence of m C cells has phase advance $n\pi$. In addition, each H section is tuned to π, so that the back-to-back pairs forming insertions (H,-H) are transparent. Any sextupoles m C cells apart are then exactly in antiphase, even if insertions intervene (no sextupoles are installed in the H sections in these lattices). To ensure a non-integer tune around the whole ring, the self-compensating condition is relaxed in selected sections, often in the long straights.

The lattice OCT_5/12 has 2 superperiods, each consisting of 1 long straight, 3 short straights and 4 identical 5BA 45° arcs with three 11.25° dipoles and two 5.625° dipoles; the lattice functions are shown in Fig. 2. In this case *n/2m* = 5/12 and the phase advance over any 90° bend is 9 π. The sextupoles are arranged in five separately powered families. All the defocusing sextupoles form one family while the focusing sextupoles are divided into four families (0,1,2,3) arranged (Fig. 2) ABBC = 0113 and 3220 in alternate octants. A number of other groupings were tried, but this proved to be the most effective. Dividing the sextupoles into more families did not provide any significant benefit.

For the lattice OCT_7/16 each octant contains 4 C cells with 9° dipoles and two H sections with 4.5° dipoles. With *n/2m* = 7/16 the phase advance over any 90° bend is 11 π. The focusing sextupoles are arranged 01113 and 32220 in alternate octants. With the number of dipoles per octant being even (6 in this case) inclusion of a s.c. dipole breaks the symmetry of the octant a little. The large on-momentum dynamic apertures shown in Table 1 were obtained at optimum conditions - C cells tuned to $(7/8)\pi$ and the horizontal beta functions of the ring having an exact 8-fold symmetry.

A. Resonance Correction and Nonlinear Dynamics

For the self-compensating choice of horizontal tunes described above some of the driving terms of the lowest order nonlinear resonances are automatically zero no matter how the different families are excited. The rest of the third-order resonance terms, and also some selected fourth-order terms, were minimized using COSY∞ to improve the dynamic aperture and the chromatic stability.

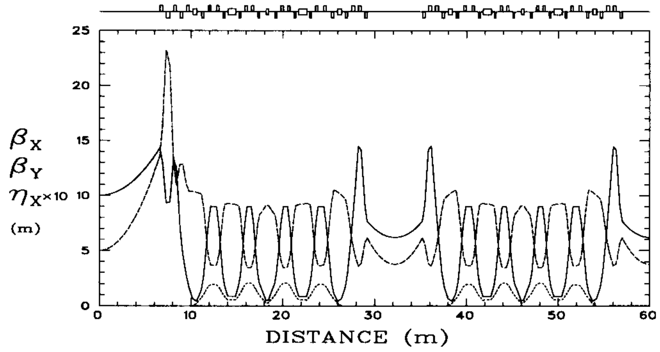

Figure. 2. Lattice OCT_5/12 (1/4 ring) with tunes ν_x=18.37, ν_y=6.4, emittance 3.6 nm.

In principle further improvement of the nonlinear behavior is possible if a similar self-compensating scheme is applied in the vertical plane. The lattice OCT_5/12 provides such a choice for the vertical phase advances, namely:

± for the C-cell $\mu_x = 2\pi/6$

± for the (H,-H) cell $\mu_y = 2\pi$.

Due, however, to increased chromaticity and sextupole strengths we did not obtain a better acceptance.

For a full cancellation of the terms driving third-order resonances, the phase advances of C cells must satisfy

$$\mu_x = \mu_y \text{ or } \mu_x = \pi - \mu_y$$

The first condition cannot be achieved for this kind of cell. The second implies a vertical phase advance μ_y =2π/12 and looks possible, but has not been tried yet.

B. Lattice Flexibility

Several working points within a half-integer square of the tune diagram gave horizontal on-momentum dynamic aperture A_x equal to or even slightly larger than the geometric acceptance of the vacuum chamber. For the ªself-compensatingº horizontal tunes in OCT_5/12 the sextupole strengths required for chromaticity and resonance correction were calculated at the working point ν_x=18.2, ν_y=6.4. The natural emittance at this point is 3.6 nm.rad with hor./vert. dynamic aperture 70/70 μm.rad. A shift of the working point towards higher horizontal tunes in the interval 18.2 - 18.4 allows the emittance to be decreased to 2.8 nm.rad (the C cell tune increasing from 150° to 155°) and/or the beta values in the middle of the short straight sections to be lowered. The lattice optics also improves because, in order to compensate the increased horizontal tune of the C cells and/or short straight sections, that in the long straights approaches unity. A maximum horizontal error-free dynamic acceptance A_x =100 μm.rad was obtained if the long straight-section tune was exactly unity horizontally with the fractional part of the machine tune equally distributed over the short straight sections.

The three short (6 m) straight sections in a half ring can have

Table I

Parameters for the various lattices (working points corresponding to largest acceptance)

Lattice	SLS	OCT4	DEC288	OCT_5/12	OCT_7/16
Periodicity	2	4	2	2	4
Circumference, m	240	280.8	288	240	259.2
Straight sections	2× 18.5 m, 4×7 m	4× 14.2m, 4×6 m	2×12.6m, 2×7 m, 4×6m	2× 13m, 6×6 m	8×6.4m
Dipole bending angle	10°	11°	10°	11.25°	9°
Number of s.c. bends	6	8	6	8	8
Lattice tunes ν_x / ν_y	22.2/5.4	19.2/6.72	22.2/7.4	18.32/6.4	22.3/7.4
Hor. emittance at 1.5 GeV (nm.rad)	1.6	4.7	2.2	3.5	1.25
Dyn. aperture on-momentum, (μm.rad)	55/50	65/35	30/35	100/70	60/70
Momentum acceptance (no errors)	4%	4%	2%	6%	3%

different horizontal beta values at the i.d. position, leading to a small but acceptable loss of dynamic acceptance.

Shorter straight sections allow better matching to the insertion devices and even better optics. The maximum dynamic apertures obtained were 130/110 μm.rad (energy acceptance ±6%) for an 8.5 m long straight section (ring length 230.4 m).

C. Lattice Errors

The sensitivity of OCT_5/12 to field errors, misalignments and higher-order multipole errors was studied at the working point ν_x, ν_y=18.32,6.4 (emittance 3.5 nm.rad, error-free acceptance 100/70 μm.rad, β_x =16 m, β_y =4 m in the middle of the long straight section). Fig. 3 shows the horizontal dynamic aperture, calculated by binary search for the outermost stable particle, assuming the same r.m.s. errors as the SLS [1]: transverse displacement 0.1 mm, rotation about beam axis 1 mrad; field deviation (except dipoles) 0.1%. Both the horizontal acceptance and the momentum acceptance are about 50% larger than those of the SLS hexagon.

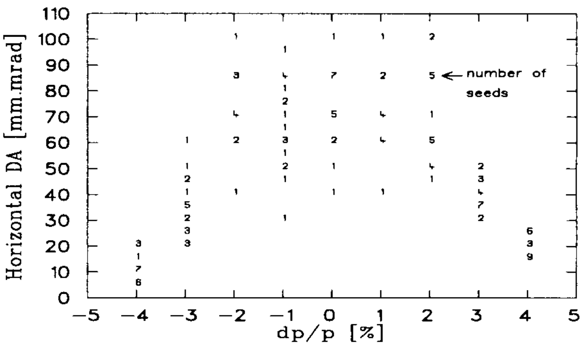

Figure. 3. Horizontal dynamic aperture of OCT_5/12

The dynamic aperture has also been studied for the tolerances used in the ALS design [4]:

± r.m.s. misalignments for all elements (cut at 2σ): transverse 0.15 mm, rotation 0.5 mrad, tilt rotation 1 mrad, field deviation 0.1%.

± multipole content as quoted in [4] with only one exception - no random octupole component is generated; the systematic octupole in the quadrupoles is one half the tolerance limit quoted in [1]: $b_{oct}/b_{quad} = 3\ 10^{-3}$ at 35 mm.

With these errors the on-momentum dynamic apertures (hor./vert.) were as follows: with sextupoles only - 100/70 μm.rad; with added multipole content to quadrupoles and bends - 85/55 μm.rad; with all multipoles and misalignments and after closed-orbit correction - 37/25 μm.rad (assuming minimum values obtained from 20 seeds).

IV. CONCLUSIONS

In summary, new lattices have been found with comparable or better optical performance than the original SLS and with more straight sections.

References

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