AN ADVANCED LIGHT SOURCE PROPOSED FOR THE SOUTHEASTERN USA

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Abstract

A study is being made for a new high performance regional light source for the Southeastern USA. It must be economical to construct and operate yet provide high brightness beams from its Insertion Devices. These will need to span both the soft X-ray region (1-2 keV) and the X-ray region up to at least 13 keV. A high brightness 3rd generation source is described which has a beam emittance less than 10 nm rads at an energy of 2.5 GeV. Using a lattice cell derived from the Theoretical Minimum Emittance type, this performance is achieved in a circumference of less than 170 m. The lattice uses vertically focusing gradient in the dipoles. The parameters are presented of both a 12 cell double bend design and a 10 cell triple bend. The dynamical stability of both lattices is described together with the beam performance from an anticipated insertion device. The current status of the proposal is explained.

INTRODUCTION

At this time CAMD, a 1.3 GeV second generation storage ring in Baton Rouge, Louisiana, is the only synchrotron light facility in the southeastern USA. It has operated successfully since 1992 in support of a growing and diverse research program mainly by scientists from the southeast. A study is being made for a new high performance source which would cater for the increasing demand for synchrotron light in the region. In keeping with its role as a regional source, it must be economical to construct and operate, yet provide high brightness beams from its Insertion Devices. For the expected research applications, the output must span both the soft X-ray region (1-2 keV) and the X-ray region up to at least 13 keV. A third generation storage ring at 2.5 GeV would be a suitable source satisfying all requirements, and has been studied by a small group based at CAMD for the past year.

LATTICE OPTIONS

Modern light source designs in the energy range 2 to 2.5 GeV achieve beam emittances below about 10 nm rads, although generally with circumferences greater than 250 m. In order to produce comparable performance from a source with a circumference below 200 m, to minimize the capital cost, a very low emittance lattice is required. The Theoretical Minimum Emittance (TME) type [1] has recently been applied to the designs of both the Australian [2] and the Canadian Light sources[3], with good results. It was decided to base the new study on a TME. Although the TME cell is not an achromat and there is non-zero dispersion in the ID straights, the overall beam brightness is higher than would be obtained with an achromatic cell due to the lower emittance.

To further reduce the cost of the source, most of the vertical focusing is obtained from a suitable gradient in the dipoles, thereby removing the need for some families of quadrupoles. A family of small vertically focusing quadrupoles is, however, included to provide for a range of betatron tune adjustment and to foresee trimming the effects of IDs.

The minimum horizontal emittance from a TME lattice is

$$\varepsilon_x(\min) = \frac{1}{12\sqrt{15}} C_q \frac{\gamma^2\theta^3}{J_x}$$

where:-

C_q= 3.84 10^{-13} m rads, γ = relativistic factor, θ = dipole bend angle, J_x= horizontal damping coefficient = 1.5.

Using this equation a 12 cell double bend lattice with dipole bend angle $\pi/12$ has a minimum emittance of 2.4 nm rads, although a practical design may be a factor 3 larger than this. Similarly, a 10 cell triple bend lattice with dipole bend angle $\pi/15$ gives 1.3 nm rads.

Double Bend Lattice

The major parameters of a double bend TME lattice with 12 cells which has been the starting point for this study are given in Table 1.

Table 1: Double Bend TME parameters

Energy (GeV)	2.5
Beam Current (mA)	400
Circumference (m)	169.2
Horizontal emittance (nm.rads)	7.74
Number of cells	12
Betatron tune (horiz; vert)	11.18; 3.15
Natural chromaticity (horiz; vert)	-19.5; -19.5
Length of straights (m)	5.0
Dipole field on orbit (T)	1.4
Dipole gradient (T/m)	-3.76
Radio frequency (MHz)	499.655

The layout of the lattice cell and a plot of the lattice functions are shown in figure 1. Both the horizontal beta function and the dispersion can be seen to reach a well defined minimum at the centre of the dipoles, which is necessary for a small minimum emittance. It also implies that the radiation source properties at the dipole centre are very good with a sigma beam size typically 100 μm by 50 μm.

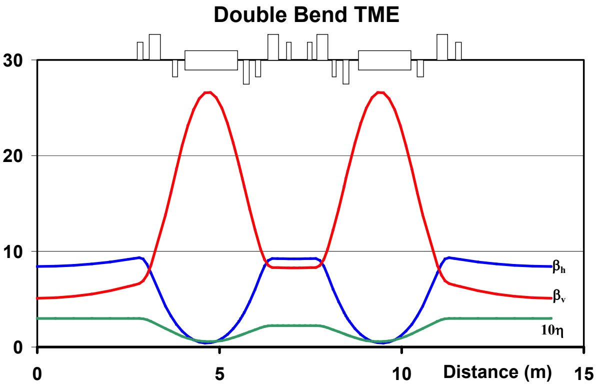

Figure 1: Double bend cell lattice functions.

Although the bending field on the central orbit is an easily achievable 1.4 T, at the inside edge of the aperture it is higher due to the vertically focusing gradient. The gradient of 3.76 T/m will increase the field to 1.59 T at 50 mm. This is a value which has been demonstrated by several other light sources which use gradient dipoles [4].

The straight length of 5 m will be able to accommodate any machine system, with the exception of single straight full energy injection. It will allow long IDs to be used, or alternatively two shorter ones in chicane. It would also be feasible to install additional quadrupoles in selected straights to modify the betas to match specific IDs, such as a superconducting undulator.

By using the small DQ trim quadrupoles and the long straight FQ quadrupoles, a good range of working points in tune space can be covered. Figure 2 shows the available space with horizontal emittance contours between the minimum of 7.7 nm rads and 10 nm rads.

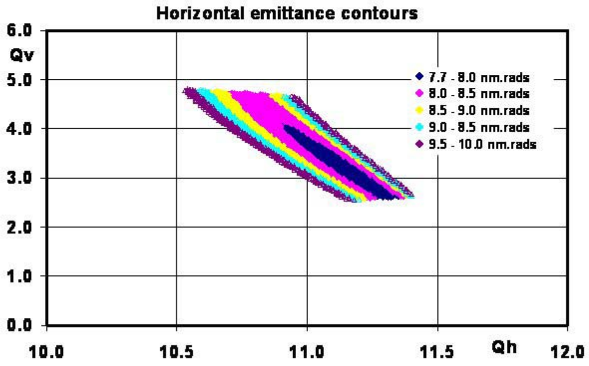

Figure 2: Emittance as a function of betatron tune for the Double Bend Lattice.

Matched zero dispersion straight

The use of top-up mode injection has clear advantages and it is likely that new light sources will be designed from the outset to use it. The optimum is full energy injection with all elements included in a single straight and for an energy of 2.5 GeV the length of the straight needs to be about 7.0 m.

A version of the 12 cell double bend lattice has been designed with two 7.0 m straights matched in a racetrack configuration. It was first necessary to match the dispersion to zero and this has been done using half length dipoles. For economy these have been given exactly the same gradient as the regular lattice dipoles. The beta functions were then matched using a quadrupole triplet at each end of the straight. The lattice functions are well behaved and are shown for one quadrant of the racetrack in figure 3. However, due to the extra length of the straights and the additional magnets for matching, the circumference of this racetrack arrangement has grown to 190.8 m.

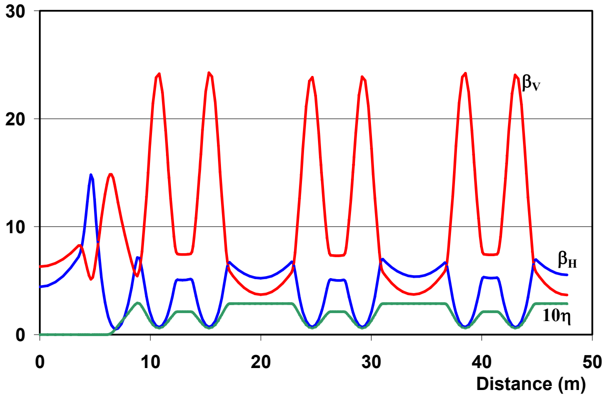

Figure 3: The Double Bend with a 7.0 m zero dispersion straight. One quarter of the lattice is shown.

Triple Bend Lattice

As is well known, and shown clearly in the equation given earlier for minimum emittance, reducing the bend angle per dipole reduces the emittance as the cube of the angle. To explore the possibility of reducing significantly the emittance, a version of the new source has been studied which has 3 dipoles per cell and is referred to as the Triple Bend lattice.

Changing to a Triple Bend cell increases the circumference due to the increased overhead of additional quadrupole and sextupole magnets, although the total length of bending magnet remains unchanged. For this reason the number of cells in the Triple Bend is 10 so that there are 30 dipoles compared with 24 in the double bend. The anticipated emittance reduction will therefore be $(24/30)^3$, or almost a factor of 2. To further limit the circumference the straight sections are restricted to just over 4 m.

The lattice functions of the Triple Bend cell are shown in figure 4. They are very similar in magnitude to those of the Double Bend shown in figure 1. Small trim quadrupoles are again included for tune adjustment, but for matching the asymmetry in the cell it is found essential to have the trims adjacent to the centre dipole arranged as horizontally focusing. This lattice gives a horizontal emittance of 4.6 nm rads, which as expected is about half that of the Double Bend.

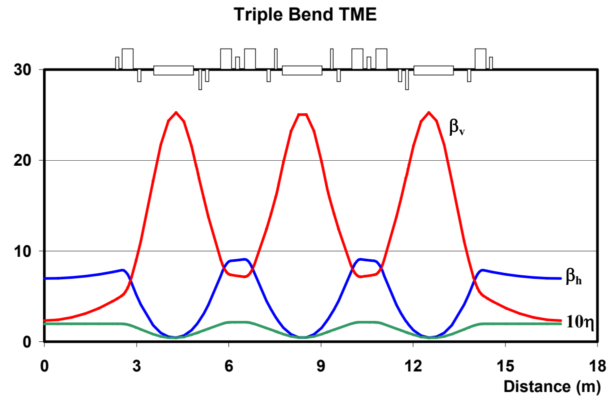

Figure 4: Triple Bend lattice functions

The major parameters of the Triple Bend, where they differ from those of the Double Bend, are shown in Table 2. It should be noted that the gradient required in the dipoles is larger than in the Double Bend, due to the stronger focusing. If the maximum field at the inner edge of the aperture is to be kept at no more than 1.6 T, the aperture will be restricted to 40 mm.

Table 2: Triple Bend TME parameters

Circumference (m)	168.0
Horizontal emittance (nm.rads)	4.56
Number of cells	10
Betatron tune (horiz; vert)	13.22; 4.18
Natural chromaticity (horiz; vert)	-22.4; -24.5
Length of straights (m)	4.44
Dipole gradient (T/m)	-5.05

DYNAMIC STABILITY

The dynamic aperture of the Double Bend is shown in figure 5 by the solid curves, whilst the Triple Bend is shown dotted. The calculations were made with 2 families of sextupoles set for zero chromaticity and for electron momentum deviations of -2%, 0%, +2%.

It is seen that the Double Bend has excellent dynamic aperture, whereas the Triple Bend is only adequate. It could be improved with additional sextupole families.

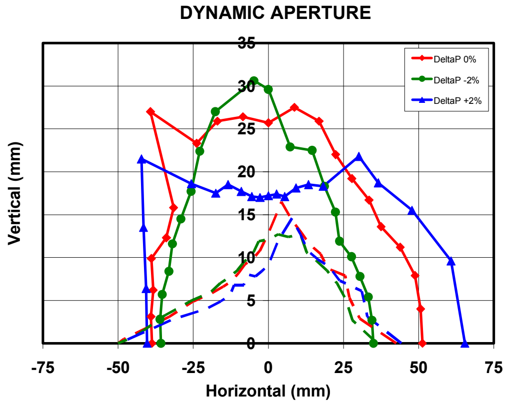

Figure 5: Dynamic aperture as a function of momentum

The dynamic aperture calculations have been verified by tracking particles as a function of starting position for 1000 turns, as shown in figure 6 for both lattices

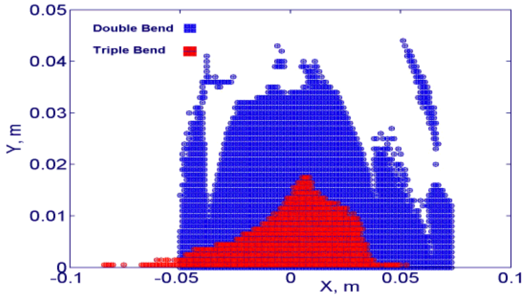

Figure 6: Tracking over 1000 turns for both lattices.

INSERTION DEVICE OUTPUTS

The use of undulator harmonics up to the 5th has been demonstrated at various facilities. As ID technology improves it is expected that even higher harmonics will be used, perhaps up to the 9th. Figure 7 shows the output tuning curves calculated for a superconducting undulator (like the U14 device at SSRL) in the Double Bend This has a 14 mm period, gap of 5 mm and length of 1.4 m.

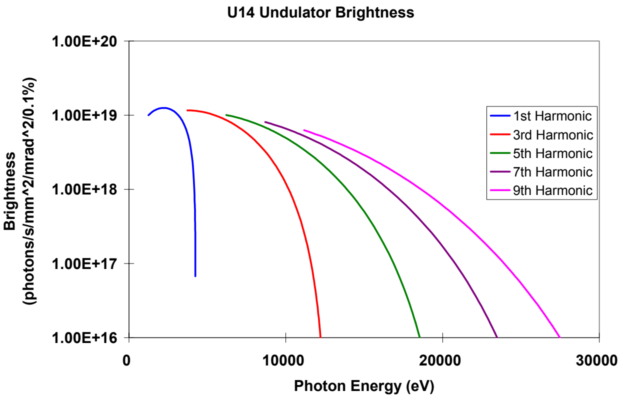

Figure 7: Undulator output for U14 in the Double Bend.

Although these outputs are theoretical, and in practice will be less due to ID errors and energy spread in the electron beam, figure 5 shows that very high brightness beams can be generated with this source. In the Triple Bend lattice the brightness shown in figure 7 will be a factor 3 higher.

STATUS

It is apparent that a small, economical, light source can be designed which is capable of a very high performance. The studies will be continued by the team based at CAMD and later this year a proposal will be made to the DoE as the first step in obtaining funding.

REFERENCES

[1] A Ropert, CERN Accelerator School, 1996. CERN 98-4
[2] J W Boldeman et al, Proc EPAC02, p 650
[3] L O Dallin et al, Proc PAC97, p 716
[4] L O Dallin et al, Proc EPAC02, p 2340