AN ALTERNATIVE LATTICE DESIGN FOR A COMPACT LIGHT SOURCE RING

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Abstract

A 26 meter circumference 1.5 GeV electron storage ring, designed to deliver x-rays with a critical energy of 10.4 keV, and has been proposed for the UCLA campus. This ring has twelve 6.9 T superconducting dipoles grouped in pairs. Each pair bends the beam sixty degrees. The quadrupoles and sextupoles are conventional. The alternative ring design presented in this report would have twelve separate 6.9 T superconducting dipoles that bend the beam thirty degrees each. Although this ring would have a larger circumference (about 36 meters) and more focusing elements, it would have a smaller emittance and consequently it would be a brighter source of x rays. As with the smaller ring, the focusing elements would be conventional. The x-ray power from the alternative ring delivered to the users is expected to be much higher than that from the smaller ring.

1 BACKGROUND

UCLA has proposed to build an ultra compact light source (UCS) on the campus. The electron storage ring produces synchrotron light within 6.9 T bending magnets. It would have an energy of 1.5 GeV and a circumference of 26 meters[1,2]. The compactness of the ring is achieved by pairing the 30 degree bending magnets to form six bending stations. Synchrotron light is extracted from the downstream dipole. The synchrotron light from the upstream magnet is absorbed by the downstream dipole vacuum chamber. The beam current in the machine is limited by the amount of synchrotron radiation that can be absorbed by the downstream magnet and its vacuum chamber. The compact storage ring has a race track structure about 10.8 meters long by about 5.5 meters wide.

Each arc in the baseline machine consists of six 30 degree superconducting dipoles, four conventional room temperature quadrupoles and six conventional sextupoles. The dipoles are grouped in three pairs; each pair share a common cryostat. Conceptually, the arcs of the ring are built up of three cells, where the outer two cells are truncated beyond the two dipoles. The beam emittance of the ring is entirely determined by the arc lattice. The baseline ring has two different straight section between the two arcs. One side of the race track has seven quadrupoles with short straight sections between them. This region will contain RF Cavities. The other side of the race track has eight quadrupoles, one 1.6 meter long space and two 0.8 meter long spaces. This side of the race track will be used for injection. A schematic representation of the baseline UCS ring is shown in Figure 1

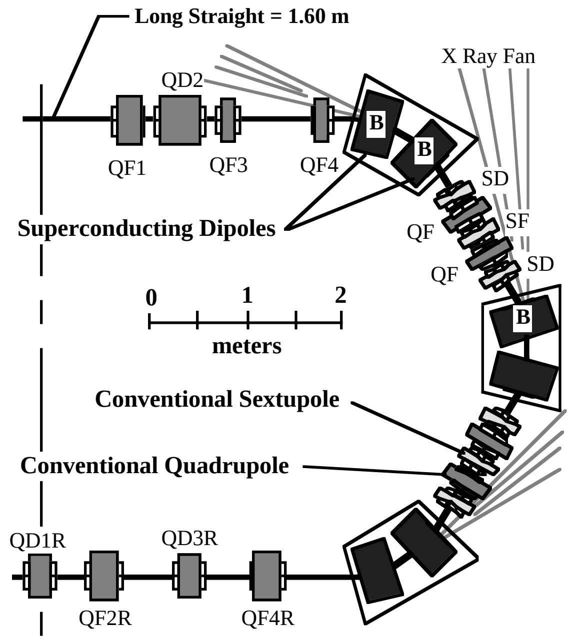

Figure 1 A Schematic Representation of Half of the Baseline UCLA Ultra Compact Light Source

2 THE ALTERNATIVE RING DESIGN

The design of the alternative ring is driven by the desire to extract the synchrotron radiation from all of the dipoles so that beam current can be increased and more x-rays can be sent to more users. There is also a desire to reduce machine emittance so that the vacuum chamber throughout the ring can have the same cross-section. As a result, the quadrupoles and sextupoles would all have the same aperture. The number of types of quadrupoles would be reduced to two and there would be only one type of sextupole. The reduced emittance lead to a smaller beam size in the dipoles and brighter x-ray beams.

The alternative ring has six identical 6 meter long cells. Thus the periodicity of the machine is six as compared to one for the baseline ring. Each of the six cells contains two 30 degree superconducting dipoles. Each cell has a 1.34 meter long drift space (between two quadrupole doublets) and a section that contains all of the chromaticity sextupoles. The sextupoles surround QF3 focusing quadrupole, which forces the dispersion to be zero in the long straight section. The dipoles have parallel faces that provide vertical edge-focusing.

The ring has six 1.34 meter long drift spaces. Three adjacent long straight sections can be used for injection (one for the septum and two for kickers that are three quarters of a betatron wave length from the septum in the horizontal direction. One or two of the other long straight sections can be used for RF cavities. This leaves one or two straight sections that can be used for insertion devices. The x-rays from the insertion devices would travel through the downstream dipole. The insertion device x-rays would be at the edge of the x-ray fan from the downstream dipole. Figure 2 shows a schematic representation of half of the alternative compact light source storage ring.

The x-ray fan shown in figure 2 represents about half of the x-rays produced in each of the bending magnets. The quadrupoles are assumed to be of the figure of eight type. This type of quadrupole is open along the mid-plane to allow for the passage of x-rays to the user. By using quadrupoles and sextupoles that are open on the mid-plane, 70 to 80 percent of the x-ray fans can be transmitted to the users.

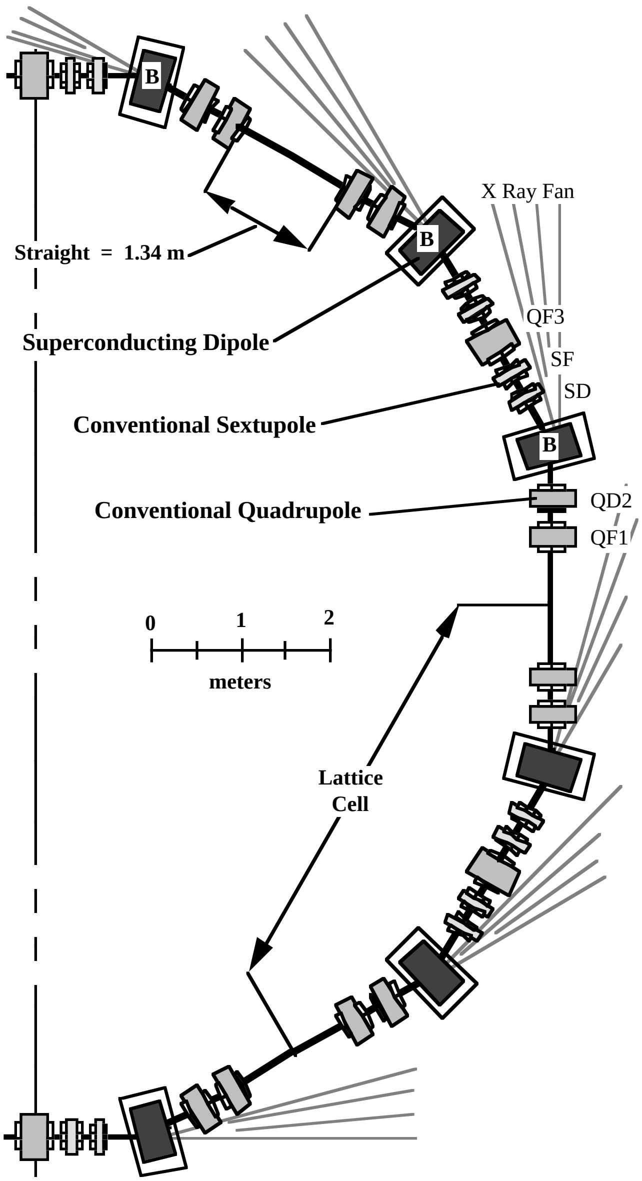

Figure 2 A Schematic Representation of Half of the Alternate Compact Light Source Ring

Table 1 A Comparison of the Lattice Parameters for Two 1.5 GeV Compact Light Source Rings

PARAMETER	Baseline Ring	Alternative Ring
Maximum Energy (GeV)	1.5	1.5
Injection Energy (GeV)	0.1	0.1
Max. Beam Current (mA)	50	100
Ring Circumference (m)	26.0	36.0
Bend Radius (m)	0.7257	0.7257
Dipole Length (mm)	380	380
Dipole Induction* (T)	6.984	6.894
x-ray Critical Energy* (keV)	10.4	10.4
Number of x-ray Stations	6	12
Extracted x-ray Power* (kW)	15.4	61.6
x-ray Brightness** (MWm^{-2})	0.51	1.71
Number. of Long Straights	1	6
Long Straight Length (m)	1.60	1.34
Machine Periodicity	1	6
Number of Cells	6	6
Number of Bend Stations	6	12
Number of S/C Dipoles	12	12
Dipole Pole Width (mm)	180	176
Dipole Cold Gap (mm)	40	40
Number of Quadrupoles	23	30
Quadrupole Dia. (mm)	Variable	33.2
Number of Sextupoles	12	24
Sextupole Dia. (mm)	Variable	33.2
Horz. Op. Emittance* (nm)	2110	309
Vert. Op. Emittance* (nm)	234	34
Horizontal Tune	3.17	4.42
Vertical Tune	2.57	2.38
Horizontal Chromaticity	-2.22	-5.24
Vertical Chromaticity	-5.24	-7.40
Max. Horizontal Beta (m)	3.09	5.62
Max. Vertical Beta (m)	6.66	5.54
Max. Dispersion (m)	1.29	0.62
Energy Loss per Turn* (MeV)	0.62	0.62
RF Voltage (MV)	2.5	1.2
RF Frequency (MHz)	500	500
Energy Spread (parts in 1000)	1.52	1.52
Bunch Length* (mm)	30	8.1
Horz. Damping Time* (ms)	0.41	0.57
Vert. Damping Time* (ms)	0.42	0.58
Energy Damping Time* (ms)	0.21	0.30
Quantum Lifetime (s)	$2.2x10^8$	$>1x10^{10}$

* at the full design energy of the machine
** at full design energy and 5 meters from the dipole

3 DISCUSSION

Table 1 compares the lattice parameters for the baseline ring and the alternative design. Both machine have a maximum energy of 1.5 GeV and an injection energy of 0.1 GeV. A microtron is assumed for the injector for both cases. The beam current in the baseline case is limited by heating due to x-rays from upstream dipole of the dipole pair in the vacuum chamber of the second dipole. The Alternative ring design has no such limitation. With correction, the beam current in the alternative machine might be increased a factor of two or three. The increased periodicity results in an emittance that is a factor of seven lower than the base line case. As a result, the beam aperture of all of the dipoles and quadrupoles is reduced by almost a factor of two. The quadrupoles and the sextupoles can all have the same design aperture. As a result, there are two types of quadrupoles and one type of sextupole. All of the quadrupoles in the ring can have the same cross-section. Twenty-four quadrupoles are 200 mm long while the other six are 300 mm long. All of the twenty-four sextupoles are 100 mm long. All of the quadrupoles and sextupoles have a pole induction that is less than 0.6 T. As a result, the magnets should track very well during the acceleration phase of the storage ring operation.

The dipoles in the alternative ring are not much different from the baseline ring case. The proposed dipoles for the ring are similar in design to magnets proposed by P. Vobly INFN Novosibirsk[3,4,5]. The horizontal aperture of the dipole is dominated by sagita and the x-ray fan out of the upstream part of the dipole. A conservative dipole design calls for a cold pole width of 176 mm. If the good field region of the dipole covers 90 percent of the pole width, the beam position can be shifted and the pole width reduced to 155 mm. The cold gap of the dipole did not change from the baseline case (despite reduced beam emittance) because the vacuum chamber inside the dipole has been designed to be identical to the vacuum chamber in the other elements, in order reduce the impedance. If a different vacuum chamber dimension was used in the dipole, the magnet cold gap could be reduced from 40 to 32 mm. The cost of the dipoles is driven by the pole width.

The energy loss per turn is 0.62 MeV per turn for both rings. The RF voltage for the alternative ring is lower than for the baseline case. The bunch length for the baseline case is 30 mm, compared to 8.1 mm for the alternative lattice. It is assumed that one would use two 500 Mhz RF cavities to provide the needed RF voltage and power for the light source. The increased x-ray power extracted from the alternative machine is due to an increase in the beam current and the fact that the x-rays are completely extracted from all twelve dipole magnets. Since the x-ray power is not limited by cooling, the extracted x-ray power will continue to increase with increased beam current. The increased brightness of the alternative ring is due to a combination of increased beam current and reduced beam size in the dipole magnet, due to a lower emittance.

For both rings, 10 percent coupling between the vertical and horizontal emittances is assumed. The alternate ring, with constant aperture dipoles, quadrupoles and sextupoles, permits the beam to be fully coupled and still maintain a 15 sigma margin around the beam within the dipoles. The margin for the beam in the QF1 quadrupole would be 11 sigma. The margin in all other elements would be 15 sigma. In most respects, the alternative ring design is more conservative than the baseline case. In both cases, the dipoles are expected to operate at about 88 percent of their design critical current when the machine operates at its design energy.

The dynamic aperture, measured in uncoupled sigmax units and fully coupled sigmay units, is about 20 sigma, which corresponds to about 30 mm. The tune variation is within 0.01 for relative momentum deviation of ±2 percent.

4 CONCLUSIONS

The alternative machine appears to be a better machine at its design energy than the baseline machine. The x-ray brightness and the amount of x-ray power available to the experimenter could be as much as an order of magnitude higher for the alternative ring operating at high beam currents. The alternative ring has the potential to serve more users with brighter x-ray beams.

The major problem with the alternative ring design is its size. The circular alternative ring is approximately 12 meters in diameter, compared to the 6 by 11 meter race track baseline ring. The increase in size may or may not reflect negatively on the cost of the machine. However, since the alternative design uses a large number of identical elements, its cost may not be greater than that of the baseline ring. More engineering is needed in order for the cost either ring to be accurately cost estimated. The alternative ring design has not been optimized. It is quite possible that the alternative ring can be made smaller without affecting performance. Further work should be done to design a ring using the alternative ring lattice that has a circumference from 32 to 33 meters.

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