LIGHT SOURCES OPTIMIZED WITH SUPER BENDS*

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Abstract

Before insertion devices (IDs) were used, small storage rings with dipole-magnet-only sources were called second-generation light sources. With today's technology, e.g. superconducting dipole magnet of 5 T (e.g., ALS's Superbend [1]), one could make a smaller ring of, say, 60-m circumference with substantial brightness for dipole-magnet beams. Without IDs, these optimized sources would be designated as between second and third generation. Such rings don't exist yet, but their concept can be compared with other types of compact light sources. Typical parameters of such ring would be 60-m circumference, 2 GeV, several 5-T dipole sources in TME-like cells, and 4×10^{13} photons/s/0.1% BW at 1 Angstrom. The number of beamlines is variable, but potentially very large, only limited by funding.

INTRODUCTION

One can group light source storage ring concepts into four categories:

1. 3rd generation light sources, which are large storage rings optimized for high-average-brightness hard and soft x-rays with a large number of users,
2. smaller storage rings with only dipole magnet sources (i.e. no insertion devices – IDs) that can produce hard x-rays at high flux,
3. very small and low-energy ring with two superconducting dipoles producing EUV for lithography, say, and
4. very small rings used for short-term storage in Inverse Compton Scattering sources.

The first type requires enormous resources to build and requires a very large group of users gathered from far and wide to justify its existence. The second type is the subject of this paper. It is smaller, cheaper and of course less capable than a 3rd generation source, but it may have a user base in smaller regions of a country where travel is of short distance. The third is of less interest because the source can't produce hard x-rays in sufficient quantity[1]. The Inverse Compton Scattering (ICS) sources are much smaller than the dipole-magnet only sources, but they can only have typically one or a few beamlines. The cost of the facility must include a complex laser system.

Large storage rings have many desirable features and are expensive, but the expense is shared by many beamlines. They range in cost from \$100 to \$1000M in today's dollars. The annual operating cost is \$30 to \$120M, roughly one tenth of the initial cost. Because of the circular nature of the source, there can be many beamlines, typically 20-60. This amounts to a cost per beamline of \$5 to \$20 M for construction and of \$1 to \$2 M for annual operations. With a range of 1000 to 5000 users per light source, the cost per experiment is \$20 to \$30 k. The beam parameters, cost effectiveness, reliability of large storage rings are well documented. The following is a list of features, not necessarily unique to these sources:

- High average brightness (of order 10^{20} b.u. for 12 keV photons for APS and ESRF) and flux
- High repetition rate (5 MHz to 500 MHz)
- Simultaneously serves a large number of users with multiple requirements
- Stability in position, angle, beam size, current and energy
- Wide photon spectrum from IR to hard x-rays, with easy and rapid tuneability, and polarization control

As the circumference is made larger, the optimized emittance is smaller, which allows higher x-ray beam brightness. This optics property can be exploited for designing an ultimate large-circumference storage ring light source. However the purpose here is to find a low cost storage-ring solution that produces the types of x-ray beams that other proposed compact light sources are producing. Reducing the circumference will reduce the cost and almost certainly reduce the brightness of the ring, but the flux may be preserved.

SMALLER 3RD GENERATION RINGS

With today's superconducting magnet technology (e.g. ALS Superbend[1]), one could make a smaller ring with substantial brightness for dipole magnet beams. Without IDs, these optimized source would not be called 3rd generation sources, but rather "Compact Light Sources." Such rings don't exist (yet), but can be conceptualized for comparison with the other types of compact light sources. The main inspiration is the ALS Superbend technology,

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[1] Storage ring Helios 2 by Oxford Instruments is used at the Singapore Light Source [2]. It has two 4.5 T dipoles, an energy of 700 MeV, and an emittance of 1.3 mm-mrad. The photon spectrum is limited to EUV.

and the secondary inspiration is the commercial production of booster synchrotrons of present 3rd generation light sources. Another inspiration is the desire to push emittance further down with aggressive lattice concepts such as multi-bend achromats or theoretical-minimum emittance cells.

We found several references by A. Garren and others [3, 4, 5, 6], and a project to build a 135-m 2-GeV light source for in Kazakhstan [7] with 8.5 T dipoles and TBA structure. Garren's rings are in general 1.5 GeV in energy, 10 to 36 m in circumference and with superconducting dipoles of 6.9 T. They are presented in quite some detail. The proposed rings are meant to produce a lot of flux for industrial and medical application, thus there is not really an emphasis on high brightness photon beams. The lattices, with typically 6 to 12 dipoles and appropriate number of quadrupoles and sextupoles, have been optimized for dynamic aperture, emittance (given the dipole angle), ring size and straight sections for rf and injection. However such small rings with few dipoles cannot produce a low emittance, which is why it would be useful at this time to revisit the concept of dipole-source-only ring, perhaps trading off a little compactness for higher brightness.

Our starting point is the Superbend of ALS (see Figure 1 with a 10-degree superconducting 5-T dipole that supports four beamlines, which establishes that a high density of beamlines is feasible around a ring. Note that the dipole beam is fan-shaped in contrast to a cone for an ICS source. The preference of a fan or a cone is application dependent. The parameters of the ring source would be:

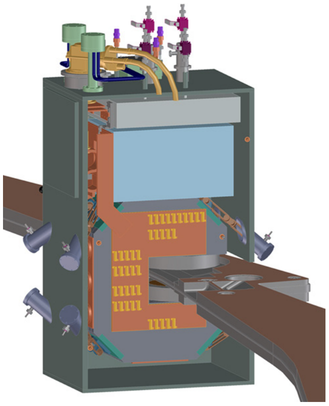

Figure 1: 3D drawing of a Superbend at ALS.

- 60-80 m circumference
- 1.5 - 2 GeV
- Several 5 T dipole sources
- 10 nm or lower emittance
- 500 mA or more stored current at least 10 dipole magnet beamlines (half on superconducting magnets)
- Flux: 4×10^{13} photons/s/0.1% BW at 1 Angstrom or 4×10^{15} photons/s/10% BW

The number of beamlines is variable and depends on funding. One could plan to have up to 80 beamlines (this is actually realistic because each beamline takes up a few milliradians of arc and the radius of the ring is small) but only build 10 beamlines initially or simply build 10 and no more after that. If one has lots of beamlines, then the overall facility cost is determined by the number of beamlines, not by the accelerator.

The flux would roughly duplicate that of the present ALS Superbend source (see Figure 2).

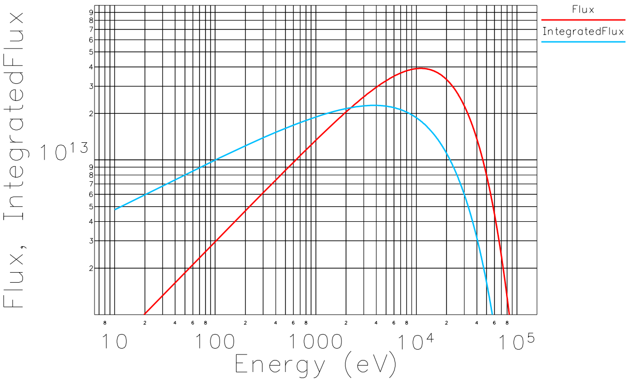

Figure 2: Flux from a 5-T dipole and 2 GeV beam. Units are photons/s/0.1%BW/mrad^2 and photons/s/0.1%BW/mrad for flux and integrated flux respectively.

The impedance of such rings is expected to be smaller than that of a 3rd generation light source because there are no IDs and no vacuum chamber transitions. Thus we expect much smaller impedance than in 3rd generation light sources. This may give some flexibility in bunch filling patterns. It is assumed that state-of-the art feedback systems used in present storage rings would permit the high total stored current specified above. This ring would be too large to fit in a university setting. Perhaps rings such as this one could be built regionally, close to a group of universities. A single university would be allocated its own block of beamlines that they manage, making the cost per university reasonable. The complexity of operating a superconducting device such as the Superbend in a university-like setting would be alleviated by using commercial cryocoolers, such as those in hospital MRI machines. Small ring installations such as CAMD operate superconducting wigglers/wavelength shifters.

TECHNICAL FEATURES

The storage ring will be a conventional one with no straight section, except for injection and rf cavities. The periodic cells would be theoretical-minimum-emittance type cells, which is a well-known optics.

There would be initially 10 beamlines and expandable to 80. The ring circumference would be 60 m as mentioend previously.

The position and angle stability can be made 10% of the beam size and divergence. Bunch pattern can be arbitrary, though bunch duration (rms) would be of the order of 20-50 ps. Partial circular polarization is obtained by using photons out of the midplane.

There are no challenges seen at this point until an explicit design is made. Perhaps a fast kicker for clean injection with accumulation might be necessary. Perhaps special on-axis injection might be adopted if optics design for low emittance is aggressive [8]; in that case injectors would be required to produce 500 mA in a 180 ns pulse (60 m) to fill the ring in one shot.

OPERABILITY CONSIDERATIONS

Staffing level will depend on the number of beamlines; say a total of 30 for 10-beamline ring source, with 1 staff per additional beamline.

As in other light sources, the ring will be available for user access for 5000 hours/year or more.

We expect the same reliability of the Compact Light Sources (97% availability) as existing sources.

SUGGESTED R&D TO IMPROVE PERFORMANCE

An aggressive optics design could lower the emittance or lower the cost. In addition the integrated magnet and girder designs of MAX-III and Max-IV[9], could lower the cost further. One would also have to integrate the ALS superconducting dipoles in those types of lattices.

The same is applicable to the short-term storage rings for ICS mentioned earlier. As laser cavities with high finesse and small spot size are further developed, it would be desirable to develop small beta storage ring lattices as well.

COST

The following cost estimates are based on scaling from engineering cost estimates of real projects and existing installations that were built within a national lab framework, which probably increases the cost a bit. Based on NSLS-II injector cost estimate, the ring with injector alone might be $30M, built commercially. This assumes that the booster can be placed in the same tunnel as the storage ring, which is a low cost configuration. The cost of each beamline generally depends on beam power. A regular dipole magnet beamline would be $2M. A high-power beamline like that of the ALS Superbend crystallography beamlines would cost $2.5M. Thus five beamlines of each type plus the ring and injector would make the total $53M. The operating cost of the ring alone may be $5M/year, following the 10% rule-of-thumb seen in many light sources. This figure agrees with the operating cost of the CAMD light source. The operating cost for each beamline would be one full-time beamline scientist plus incidentals; so say, $0.3M per year. The total would be $8M/year.

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