CONCEPTUAL DESIGN OF THE ARGONNE 6-GeV SYNCHROTRON LIGHT SOURCE*

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Summary

The Argonne National Laboratory Synchrotron Light Source Storage Ring is designed to have a natural emittance of 6.5×10^{-9} m for circulating 6-GeV positrons. Thirty of the 32 long straight sections, each 6.5-m long, will be available for synchrotron light insertion devices. A circulating positron current of 300 mA can be injected in about 8 min. from a booster synchrotron operating with a repetition time of 1.2 sec. The booster synchrotron will contain two different rf systems. The lower frequency system (38.97 MHz) will accept positrons from a 360-MeV linac and will accelerate them to 2.25 GeV. The higher frequency system (350.76 MHz) will accelerate the positrons to 6 GeV. The positrons will be produced from a 300-MeV electron beam on a tungsten target. A conceptual layout is shown in Fig. 1. Related papers on the Argonne Synchrotron Light Source may be found in references 1-3.

The Pre-Injector

A triode gun, operating at 50 Hz repetition rate will produce pulses of 20-nsec duration, each having a current of 3.5 A. These pulses will travel through a single cavity SW prebuncher and a tapered traveling wave guide buncher before entering an electron linac. The linac will accelerate 2.5-A pulses to 300 MeV using 6 sections of 3-meter length S-band traveling wave disk loaded waveguides.

Fig. 1. Schematic Layout of the Pre-injector System, Booster Synchrotron and Synchrotron Light Source Ring.

Table I
Nominal Linac Parameters

<u>General</u>	
Frequency	2.9985 GHz
Klystron Power	35 MW
No. of Sections/Kly	2
Beam Pulse Current	2.5 A
Beam Pulse Length	20 nsec
Repetition Rate	50 Hz
Accelerating Mode	2 π /3
W.G. Length	3 m
Energy Gain	16.7 MeV/m
<u>e⁻ Linac</u>	
No. of Sections	6
Input Current	3.5 A
Output Current	2.5 A
Output Energy	300 MeV
<u>e⁺ Linac</u>	
No. of Sections	7
Input Energy	10 MeV
Resolved Output Current	10 mA
Emittance	14.0 mm mrad (360 MeV)
Energy Spread	± 1.5 MeV

The positrons will be created by the 300-MeV electrons striking a 7-mm tungsten DESY type of production target. The DESY system routinely produces a conversion ratio, I^+/I^- , of 0.8% for 300-MeV electrons.⁴ We can safely assume that the target will have a production ratio of 0.4% and will produce at least 10 mA of positrons for each 20-nsec pulse. A solid angle of 0.32 steradian and an electron beam diameter of 3 mm will produce an initial positron emittance of 0.48×0.48 mmrad.² The accepted energy will be 10 ± 1.5 MeV.

The positron beam from the target will be focused by a high-field pulsed solenoid before being injected into the positron linac. This linac will accelerate the positrons to 360 MeV using seven 3-meter traveling waveguide sections operating in the 2 π /3 mode.

Injection and Acceleration of the Positrons in the Booster Synchrotron

The booster synchrotron has two rf systems. During injection at 360 MeV, the lower frequency system (system 1, 38.973 MHz) will be turned on at a low voltage of about 12 kV. The harmonic number is 52. The 20-nsec 10-mA positron bunches will be injected into the rf buckets at a constant bunch separation of 102.5 nsec (every 4th bucket). Only ten bunches will be injected so that the turn-off time for the injection kickers can be as long as 390 nsec. A pulse rate of 50-Hz and 10-mA per pulse gives 1.25×10^{10} positrons injected in 0.2 sec.

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The longitudinal phase space area of the positrons in each filled bucket will be 0.068 eV sec. After the ten pulses have been injected, the rf voltage will be increased to 150 kV, causing the bunch length to decrease to 8.9 nsec. As the magnetic field is increased and the positrons are accelerated at a constant rate of 14.1 GeV/sec (18.62 keV/turn), the bunch length will be damped by radiation and acceleration. Analysis shows that the bunch length at 2.25 GeV should be about 2 nsec. During the acceleration to this energy, the cavity voltage will be raised to 200 kV.

The 2-nsec bunch length at 2.25 GeV is small enough to fit inside the buckets of a higher frequency 350.76 MHz ($h = 468$) rf system (system II). During the acceleration by rf system I, system II must be detuned to a lower frequency to prevent excitation of the Robinson instability. At 2.25 GeV, system II will be turned on with a rise time of 40 μ sec while system I is turned off with a time constant of 160 μ sec. The initial voltage of system II will be about 1.0 MV. During acceleration to 6 GeV, the voltage will be raised uniformly to 5.2 MV. At this voltage, the bunch length at 6 GeV will be about 93 psec and the energy spread about $\pm 0.095\%$. The quantum lifetime for loss from the bucket will be 0.51 sec.

The ten pulses will be extracted individually by a fast kicker magnet operating at 50 Hz. The exact timing time will be controlled so that each pulse will be injected into the desired bucket in the SLS ring. The 20 nsec between each extracted pulse is about 2.5 time constants for horizontal damping in the SLS.

The total time required for 1 Booster cycle will be 1.2 sec. Since each booster cycle is expected to yield 1.25×10^{12} positrons, the total time required for an initial fill of the SLS ring to 5×10^{12} (300-mA) will be about 8 min.

Booster Synchrotron

The booster synchrotron design, Fig. 2, has a circumference of 400 m and is composed of 50 FODO $\pi/2$ cells. The shape is that of a race track with two long straight sections. The calculated natural emittance is 0.1 mm mrad. There are 44 full-size magnet cells. Four half-magnet cells are used to match the dispersion function by "killing" it in the long straight sections. Each of the full-size magnets is 2.3 m long and has a field strength that varies from 0.041 T at 360 MeV to 0.683 T at 6 GeV. The focusing and defocusing quadrupoles can have equal gradients producing a constant tune separation ($v_y - v_x$) of 0.12.

Each straight section contains 3 FODO cells. One cell in each straight section will contain fast kicker magnets and septum magnets required for injection and extraction. The free space between the quadrupoles is 3.5 m. One of these will contain the low-frequency cavity used for injection and acceleration to 2.25 GeV. Two more will be occupied by the 5.2-MV high-frequency rf system used for acceleration to 6 GeV. This leaves a total of five unoccupied 3.5-m sections which is more than enough space for additional cavities for possible acceleration to 7 GeV.

Light Source Ring

The light source ring design has a circumference of 800 m and is very similar to that of the European Synchrotron Radiation Facility.⁵ There are 32 dispersion-free straight sections, 30 of which will

Fig. 2. Beta and Dispersion Functions for One Quadrant of the Booster Synchrotron.

Table II
6 GeV Booster Synchrotron

Circumference	400 m
Repetition Time	1.2 sec
Periods	2
90° Cells	50
Full magnet cells	36
Half magnet cells	8
Photo cells	6
Full Magnet Lengths	2.3 m
Fields	0.04 T (0.36 GeV) 0.68 T (6.0 GeV)
Max Quadrupole Strength	15 T/m
Tunes	$v_x = 12.30, v_y = 12.42$
Natural Emittance	0.107 mm mrad
RF	
Energy Gain/Turn	18.8 keV
System I (0.36 to 2.25 GeV)	
f	38.974 MHz
h	52
V_{max}	200 kV
fs	1.8 kHz (2.25 GeV)
System II (2.25 to 6.0 GeV)	
f	350.76 MHz
h	468
V_{max}	5.2 MV
fs	14.6 kHz (6 GeV)
Max. Energy Loss/Turn	3.9 MeV
Bunch Length τ_c	93 psec
Energy Spread σ_e/E	0.95×10^{-3}
Quantum life time	510 msec

be available for wigglers and undulators. The unobstructed free space in these straight sections is 6.5 m. There are 64 bending magnets, each having a length of 2.95 m and a field of 0.666 T at 6 GeV. Thirty two of these bending magnets can be equipped with ports for additional synchrotron radiation beam lines.

The horizontal beta function structure through the magnets, shown in Figs. 3 and 4, produces a calculated natural emittance of 6.5×10^{-9} m. The two sets of triplet quadrupoles, one at each end of the dispersion-free straight sections can be tuned to provide a wide range of beta function structures in one dispersion-free straight section without disturbing the structure in any other straight section. Figure 3 shows a typical structure for undulator insertions. The structure in Fig. 4 could be used for wigglers.

Fig. 3. Typical Undulator Section for the SLS.

Fig. 4. Typical Wiggler Section for the SLS.

Table III
Synchrotron Light Source Ring

Energy	6 GeV
Circumference	800 m
No. of Insertion Regions	32
Free Length in Insertion Regions	6.5 m
Dipole Lengths	2.95 m
No. of Dipoles	64
Dipole Field Strength	0.666 T
Energy Loss/Turn	5.82 MeV
Rf Voltage	(with 16 Insertions) 24 MV
Rf Frequency	350.76 MHz
Harmonic No.	936
Synchrotron Frequency	1.55 kHz
Quantum Life Time	54 hrs.
Transverse Damping Time	8.4 msec
Longitudinal Damping Time	4.2 msec
Natural Emittance	6.5×10^{-9} m
Bunch Length	36.2 psec

Chromaticity correction is accomplished by sextupoles in the dispersion regions. Since the horizontal phase advance for each section is close to 2π , the chromaticity correcting sextupoles will drive harmful resonances that limit the dynamic aperture. Additional sextupoles interspersed between the quadrupole triplets in the dispersion-free straight sections can be tuned to cancel the harmful driving terms and restore the dynamic aperture to adequate limits.

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