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THE NSLS BOOSTER SYNCHROTRON

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# Abstract

The Booster for the National Synchrotron Light Source electron storage rings is a 100-700 MeV synchrotron with 28.35 meter circumference. Its design current is 20 mA and its repetition rate is 1 Hertz. The lattice consists of four superperiods, each containing two focusing quadrupole magnets and two defocusing bending magnets. Nominal tunes are  $v_x=2.42$ ,  $v_y=1.37$ . Small values of  $\beta_x$  and  $\eta_x$  in the bending magnets allow a damped emittance  $e_x=5.6 \times 10^{-6}$  meter radians. Details of the lattice, beam dynamics and beam injection and ejection are presented.

### Introduction

The booster synchrotron of the National Synchrotron Light Source differs from the design described in the original proposal  $^1$  in having a circumference smaller by 5.6 meters, combined-function defocusing dipoles, and only focusing quadrupoles. The changes are dictated by: 1) the planned location of the booster relative to the storage rings, requiring two ejection systems at opposite sides of the booster, and 2) the desire to minimize the floor space required by the booster. The design energy, current and repetition are unchanged at 0.7 GeV, 20 mA and 1 Hertz. This report describes the design and function of the booster. (Section I lists characteristics of the lattice. Section II describes the injection-ejection cycle. Section III describes the closed orbit correction system and provisions for diagnostics. Section IV describes the vacuum system.)

#### I. Characteristics of the Lattice

Lattice design was performed using SYNCH.<sup>2</sup> The most notable feature of the booster is the use of combined function horizontally defocusing bending magnets and separate horizontally focusing quadrupoles (Table I). This arrangement makes efficient use of space. It also places the maximum  $\beta_X$  locations in the middle of the straight sections to simplify injection-ejection (Fig. 1). Despite the use of combined function magnets, betatron and synchrotron oscillations are damped. Small values of  $\beta_X$  and  $\eta_X$  within the bending magnet result in a damped emittance of  $\boldsymbol{\varepsilon}_X=5.6 \times 10^{-8}$  m-radians.

Table	Ι.	Magnetic	Elements

			*	Effective
Name	Туре	Quantity	B, B', B''	Length
BB	Dipole	8	B=12.226 kG	1.5 m
			B'=-7.44 kG/m	
			B"=-117 kG/m <sup>2</sup>	
Q1	Quadrupole	4	B'=+64.23 kG/m	0.3 m
Q2	Quadrupole	4	B'=+87.36 kG/m	0.3 m
SF	Sextupole	4	B"=+1142.1 kG/m	0.2 m
* • •	-23 35 kC m			

\* βρ=23.35 kG-m

The ratio of currents in quads Q1 and Q2 is set to maximize the horizontal acceptance of the machine. All eight quads will be connected in series; the Q1 quadrupoles will have 30-turns of conductor per pole, while the Q2 quadrupoles will have 38-turns per pole.

The  $45^{\circ}$  bend angle and 225 degree poleface rotation angle of the booster dipole required detailed

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consideration of its optical properties. Edge focusing was treated in a thick lens approximation. A more important effect is the 8% variation in gradient along the beam path due to the fact that the beam crosses the laminations at an angle varying from  $\theta = 22.5^{\circ}$  to  $\theta=0^{\circ}$ .

The uncorrected chromaticities of the Booster are  $\xi_{\mathbf{x}} = -2.13$ ,  $\xi_{\mathbf{y}} = -3.55$ . These will be corrected to  $\xi_{\mathbf{x}} = +.5$ ,  $\xi_{\mathbf{y}} = +.5$ . A defocusing sextupole term is designed into the dipole magnet field for this purpose. Four sextupole magnets, neighboring the Q2 quads and arranged with twofold symmetry, will complete the chromaticity correction. Figure 2 shows the dependence of tune on momentum for the booster lattice with chromaticities  $\xi_{\mathbf{x},\mathbf{y}} = +0.5$  at  $\frac{\Delta p}{p} = 0$ . The curvature in the tune versus momentum is judged sufficiently small over the maximum expected momentum range of  $-.0025 \leq \frac{\Delta p}{p} \leq .0025$  at injection. Presently a reentrant 52.88 MHz R.F. cavity is being designed to accelerate the beam and replace the 222 watts radiated by the beam at 0.7 GeV. Adequate Touschek and quantum lifetimes are obtained with a peak voltage of 25 kV.

The dynamic aperture and nonlinear coupling are under study by tracking particles with SYNCH.

Table	II.	NSLS	Booster	Par	ameters

Energy Range Circumference	0.1 GeV - 0.7 GeV 28.35 m
Number of superperiods	4
Dipole bending radius	1 910 m
Nominal Tupoa, y	7 / 7
Nominal lunes: V <sub>X</sub>	2.42
vy	1.37
maximum	minimum
β <sub>x</sub> 8.63 m	1.01 m
β <sub>w</sub> 5.26 m	1.73 m
η <sub>x</sub> 1.21 m	0.41 m
Momentum compaction $\alpha$	0.106
RF peak voltage	25 kV
RF Frequency	52.88 MHz
Acceptance Horizontal	$\epsilon = 1.66 \times 10^{-4}$ meter-radian
moop and a monthly and	°x
Vertical	ε =6.11x10 <sup>-b</sup> meter-radian y
Momentun Spread	$-0.0025 \le \frac{\Delta p}{p} \le 0.0025$

# II. The Booster Cycle--Injection, Ejection

The booster will cycle at a frequency of 1 Hertz. The cycle will consist of: 1) a 0.4 second ramp from 0.1 GeV to 0.7 GeV; 2) a 0.2 second flat top to allow the beam to damp; 3) a 0.3 second return to 0.1 GeV setting; and 4) a 0.1 second quiescent period. The booster will accelerate 20 mA, or  $1.18 \times 10^{40}$  electrons, per pulse. Filling time for the VUV ring is therefore 90 seconds. Filling time for the X-ray ring is 150 seconds.

The booster itself will be filled by a Varian Linac made up of 3 accelerating sections, operating at 2856 MHz. The Linac will produce a 0.1 GeV beam with current I = 20 mA, an emittance  $\epsilon_{x,y} = 6.37 \times 10^{-8}$  meterradians, and an energy spread -0.0025  $\leq \frac{\Delta p}{p} \leq 0.0025$ . High injection-ejection efficiency is desired to minimize shielding problems. Present plans call for filling

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a single bucket in the booster. To do this, the linac pulse will be modulated at 10.58 MHz before acceleration. The beam will be injected to fill the horizontal betatron phase space of the booster.

R. Servranckx has studied injection to the booster<sup>3</sup> using analytic and computer simulation techniques. He obtained an efficiency of 81% for injection during the first nine turns of a closed orbit bump which decreased from 40 mm to 0 mm in thirteen turns. After his work, the lattice was retuned to improve dynamic aperture with sextupoles turned on. Simulation of the same injection sequence now shows 75% efficiency.

Eddy currents in the booster vacuum chamber have been studied.<sup>4</sup> The contribution from the dipole magnets is dominant. A tune shift of  $\Delta v_y$ =-1.7x10<sup>-3</sup> and change in chromaticity of  $\Delta \xi_y$ =-0.26 is expected at the beginning of the ramp.

Ejection to the X-ray ring will occur at the injection straight, while ejection to the VUV ring will occur at the opposite side of the booster (Fig. 4). Ejection will be accomplished by first slowly distorting the closed orbit to within 1 cm of the ejection septum, using the backleg windings of the bending magnets. A full-aperture fast (90 nsec) kicker will then steer the beam through the ejection septum magnet to one of the storage rings. Figure 3 shows the injected, ejected and stored beam envelopes in the injectionejection straight.

Table III, Properties of the Beam

Current Orbital Period	20 m/ 94.6	4 (1.18x10 e's) nsec
Operating Energy	0.1 GeV	0.70 GeV
Emittance $\varepsilon_x$	1.8x10 <sup>-6</sup> m-radian 6.4x10 <sup>-6</sup> m-radian	5.6x10 <sup>-8</sup> m-radian 5.6x10 <sup>-9</sup> m-radian
Energy Spread Ap P	±0.0025	±0.00037 (±1σ)
Bunch Length Energy Loss/Turn Damping Partition Damping Times T <sub>x</sub>	~ 2.6 m 0.005 keV/turn -0.67 2.46 sec	0.16 m 11.2 keV/turn .007 sec
τy τe	4.08 sec 3.05 sec	.012 sec .009 sec
Quantum Lifetime Ta	$\gg 2 \times 10^{10}$ sec	1.98x10 <sup>10</sup> sec

<sup>1</sup> Undamped beam

# III. Closed Orbit Correction and Beam Diagnostics

Expected closed orbit errors were determined using the program CLOSORB<sup>5</sup> and assuming rms magnet placement errors of ±0.15 mm and rms magnet rotation errors of 0.5 milliradian. Given these tolerances, uncorrected horizontal closed orbit errors are unlikely to exceed  $\pm 2.2$  mm and uncorrected vertical closed orbit errors should be less than ±4. mm. Three horizontal and two vertical beam position monitors will be included in each superperiod. The beam position monitors are 58mm O.D. x 149 mm cylinders cut diagonally to form two "sugar-scoop"-shaped electrodes. They will monitor beam position at currents of a few milliamps. Two horizontal and two vertical correction dipoles will be placed in each superperiod. The strength of any horizontal correction is not expected to exceed 14 G-m., and all vertical correctors will be weaker than 1A G-m. Closed orbit errors after correction should be less

than 1 mm. A toroidal beam transformer may be included to measure the beam current. Present plans call for an air core RF tickler to excite betatron oscillations while beam position is monitored using the pick-up electrodes.

# IV. Vacuum System

A pressure of  $10^{-7}$  Torr is desired in the booster. A Balzers turbomolecular pump and liquid nitrogen cold trap will be used for roughing. High vacuum will be reached using four Ultek sputter ion pumps capable of 200 Liter/sec each. The vacuum chamber will be built from segments of varying cross section. Within the bending magnets the chamber will have a 123 mm x 32 mm elliptical cross section. It will be made of 0.75 mm 304 stainless steel. Stiffening ribs will be welded to the outside of the chamber to eliminate flexing on evacuation. Outside the bending magnets, the beam pipe will be 89 mm O.D. x 1.6 mm thick stainless steel tube. Segments of ceramic chamber will be included to accommodate the fast magnetic components. The various chamber sections will be welded into a ring. Pumps and gauges will be attached using Conflat flanges.

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Figure 1.



NOTE :- BASIC CIRCUMFERENCE + 28.34624 METERS

Figure 4. Booster Assembly.