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A STUDY FOR A 6 GeV UNDULATOR BASED SYNCHROTRON RADIATION SOURCE*

G. Vignola, M. Barton, R. Blumberg, J. Galayda, S. Krinsky, A. Luccio, C. Pellegrini, A. van Steenbergen, J. Wang
National Synchrotron Light Source
Brookhaven National Laboratory, Upton, N.Y. 11973

Abstract

A partial study for a 6 GeV undulator based synchrotron radiation source for production of high brightness undulator radiation, in the Å region, is presented. The basic lattice adopted for the storage ring is a hybrid FODO Chasman-Green lattice, making use of gradient in the dipoles. We discuss also the e beam current limits and the injection parameters.

Introduction

The actual trend for a large synchrotron radiation facility is to use a 6 GeV electron storage ring with a small emittance of the electron beam and with a large number of straight section for the insertion of wiggler and undulators. A complete and detailed design for this kind of facility has been carried out by the ESRP group.[1] The European design is based on the Chasman-Green[2] lattice that has been studied extensively. From this study a number of problems associated with a low emittance C-G lattice were in evidence, and study of possible alternate magnetic lattices became important.

For these reasons we present here a study of a storage ring based on a magnetic structure recently proposed.[3] The point that we want to emphasize is that we try to pursue, where it is possible, a principle of simplicity for the architecture of the machine suggested not only by cost considerations but also by the requirement of relatively easy commissioning and operation. In addition the possibility to operate the machine at higher energy is kept open.

Characteristics of the Storage Ring

The lattice of the storage ring consists of 28 periods with 28 six meter long straight sections. One half of the standard cell is characterized by the following magnetic sequence:

$$\frac{O}{2},\ QF1, QD1, B, SD,\ \frac{QF}{2},\ SF,\ \frac{C?}{2},\ SD,\ \frac{B}{2}$$

and has reflection symmetry. The dipoles have a vertical focusing gradient with a field index n = 106.4.

The layout of one period is shown in Fig. 1:

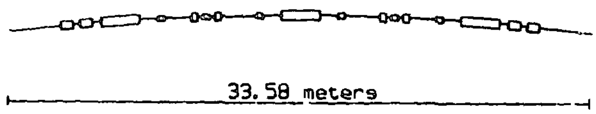

Fig. 1. Layout of one period.

The period length is 33.67 m with 20.35 m of free space and this allows easy extraction of the radiation from the insertion devices, as well as from the bending magnets. The optical functions and the beam dimensions for one period are plotted in Fig. 2 and Fig. 3, respectively, while the main ring parameters are listed in Table I.

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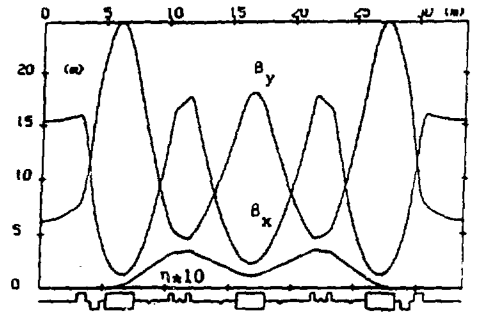

Fig. 2. β and off-energy η functions for one period.

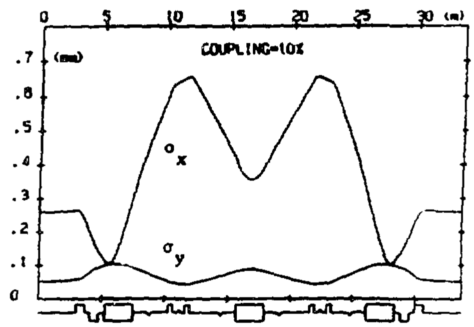

Fig. 3. Horizontal and vertical r.m.s. electron beam dimensions for one period and for 10% coupling.

Table I. Main Ring Parameters.

Energy		6 GeV
Circumference		842.78 m
Periods		28
Long straights		28x6 m
No of Dipoles		84x2.24 m
Dipole field		6683 G
Dipole central gap		48 mm
Magnetic radius		29.947 m
Field index n		106.4
No of Quadrupoles		112x70 cm
		112x35 cm
Max field gradient		111.5 kG/m
No of Sextupoles		168x40 cm
Max field 2nd deriv.		140 kG/m²
Hor. betatron tune		31.32
Ver. betatron tune		16.32
Energy loss/turn		3.83 MeV
Energy spread		.1%
Momentum comp.		4.1×10^{-4}
Hor. emitt. (0 coupl)		4.9×10^{-9} m-rad
Damping times	T_x	6.87 msec
	T_y	8.88 msec
	T_e	6.30 msec
Hor. nat. chrom.		-48.7
Ver. nat. chrom.		-31.2
Closed orbit max		
ampl. factors	PQ_x	75
	PB_x	2 mm
	PQ_y	92
	PB_y	20 mm

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The combined function dipoles should not be a serious problem because with a maximum field of ~ .67T at 6 GeV, a field index n = 106.4 and a magnetic length of 2.24 m they can be regarded as conventional. We checked with the computer code POISSON that a deviation of ~ 10^{-4} from the ideal field shape at ± 20 mm could be easily achieved.

For the chromaticity correction we use 6 sextupoles/period subdivided in two families. This approach gives a satisfactory chromatic behavior and dynamic aperture (see Fig. 4) and provides for enough flexibility to extend the number of sextupole families to possibly six for correcting the additional chromatic aberrations introduced by incorporating a variety of low β insertions.

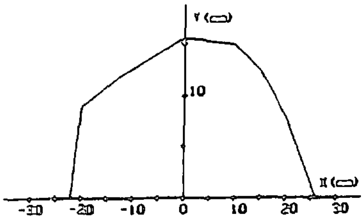

Fig. 4. Dynamical aperture as obtained with PATRICIA[4] at the long straight section midpoint for $\Delta p/p = 1\%$ and with synchrotron oscillations for a corrected value of chromaticity $\xi_H = \xi_V = 0$.

Current Limits

The threshold total average current I_L and I_T for the longitudinal and transverse coupled bunch modes are given by

$$\frac{1}{T_s} = I_L \frac{\alpha\omega_o}{2\pi E\nu_s} \frac{\sigma_\theta^{2\mu-2}}{2^\mu(\mu-1)!} R_{L,eff}^{(\mu,a)},$$

and

$$\frac{1}{T_y} = I_T \frac{ec}{4\pi E\nu_y} \frac{\sigma_\theta^{2\mu}}{2^\mu \mu!} R_{T,eff}^{(\mu,a)},$$

where T_s, T_y are the synchrotron and betatron damping times, ν_y and ν_s the vertical and synchrotron tunes, μ the head-tail mode number, a the symmetrical coupled bunch mode number, M the number of bunches and the effective resistences are related to the resistive parts, $R_L(\omega)$ and $R_T(\omega)$, of the longitudinal and transverse impedance by

$$R_{L,eff}^{(\mu,a)} = \sum_n (nM+a)^{2\mu-1} R_L[(nM + a + \mu\nu_s)\omega_o] e^{-(nM+a)^2\sigma_\theta^2},$$

and

$$R_{T,eff}^{(\mu,a)} = \sum_n (nM+a-\nu_y + \frac{\xi}{\alpha}\nu)^{2\mu} R_T[(nM+a-\nu_y+\nu_s)\omega_o].$$

$$\exp[-(nM + a - \nu_y + \xi\nu_y/\alpha)^2\sigma_\theta^2]$$

We assume that the dominant source of the coupled bunch instabilities are the RF cavities, and base our calculations on the adoption of LEP-Cavity (350 MHz) of CERN or VUV-Cavity (50MHz) of BNL. The important parasitic mode impedances for these cavities have been reported in Ref. (5), (6) and (7). To calculate T_s and T_y, we assume the energy loss due to the radiation of the insertion devices to be 30% of that at the dipole magnets. To specify the RF-voltage and the synchronous phase angle, we require the energy acceptance of the RF-bucket to be 10 σ_E.

The RF voltage and the synchronous phase angle for the 350 MHz cavity are 6.1 MV and 126.5°, and those for 5 MHz cavity are 5.3 MV and 109.8°. The results of the calculations are listed in the following tables.

Table II. Longitudinal Coupled Bunch Instabilities

PARASITIC MODES			THRESHOLD CURRENT (mA)	
F (MHz)	Q	R (Mohm)	μ=1	μ=2
FRF=350 MHZ				
508	40600	1.30	81	10713
820	40700	0.75	80	9169
1163	50400	0.33	110	3648
1204	70400	0.36	98	3027
1745	68500	0.37	71	1039
1990	68700	0.20	120	1350
FRF=50 MHZ				
507	20278	0.20	121	1470
859	5371	0.19	102	431
1300	14723	0.24	102	188
1447	9285	0.40	70	104
1539	9815	0.41	78	100

Table III. Transverse Coupled Bunch Instabilities

PARASITIC MODES			THRESHOLD CURRENT (mA)	
F (MHz)	Q	R (Mohm/m)	μ=0	μ=1
FRF=350 MHZ				
614	70800	18.0	45	5370
782	55800	19.4	42	[illegible]
1072	50100	12.4	68	[illegible]
1325	68600	18.4	45	1137
1583	68600	5.2	172	3074
FRF=50 MHZ				
507	20278	.00800	116700	1400000
579	2184	.00065	1518500	14000000

The broad band impedance may cause fast head-tail instabilities. We adopt here a crude estimate for the transverse fast head-tail mode threshold current. We assume it to be that current which is large enough to cause the rigid dipole mode frequency shift to equal the synchrotron frequency. The broad band impedance is chosen to be that of a Q = 1 resonance at frequency f_{res} = 2c/b with shunt longitudinal Z_n/n at resonance to be 1.5 ohms. The reactive part of the tansverse impedance is given by

$$X_T(f) = 1.5 \frac{2c}{b^2} \frac{1}{2\pi f_{res}} \frac{1 - 2x^2}{2x^2 + (1 - 2x^2)^2}$$

where $x = f/f_{res}$ and b = 2 cm is the effective chamber radius.

The single threshold current thus obtained is 1.9 mA for 350 MHz RF frequency and 2.1 mA for 50 MHz RF frequency.

Storage Ring e⁻ or e⁺ Accumulation Rates

For the beam injector for the storage ring two systems are under study. These are a (i) 150 MeV Microtron - 6 GeV fast cycling Booster Synchrotron electron accelerator combination and a (ii) 200 MeV e⁻ Linac - 800 MeV e⁺ Linac - 6 GeV Booster Synchrotron positron source. The reason for contemplating the use of positrons for the generation of synchrotron radiation in the storage ring is because of the deleterious effects encountered in present electron storage rings due to ion trapping in the potential well of the electrons, both in terms of substantial decrease in beam lifetime and in reducing the synchrotron radiation source brightness.

The parameters of the Booster synchrotron and Microtron preinjector, for the case of electron utilization in the storage ring, are summarized in Table IV.

Table IV. Booster Synchrotron Elementary Parameters

Beam energy	6.0 GeV
Beam current	5 mA
Repetition rate	10 Hz
Beam emittances, E_x	1.5×10^{-7} m-rad
E_y	$1.7\ 10^{-8}$ m-rad
Energy spread	. . %
Circumference	297.7 m
Revolution frequency	1.01 MHz
Preinjector, microtron:	
Energy	0.15 GeV
Intensity (~ 1 μsec pulse)	20 mA
(~ 3 nsec pulse)	40 mA
Emittances $E_x = E_y$	10^{-7} m-rad
Energy spread	0.07%
Radiofrequency; (harmonic number)	317.2 MHz ; (h=315)
No e/bunch, multibunch mode	3.9×10^{8}
No e/bunch, single bunch mode	7.6×10^{8}
Energy loss/turn	4.87 MeV
RF voltage (max), (q=1.8)	7.38 MV
RF cavities, 5 cells, (L=2.32 m)	4

For the positron source option the use of a Linear Accelerator-Booster Synchrotron combination is considered. The parameters are based on the LEP positron source design.[8] Since, however, a substantially longer pulse length is required in the present case, the electron preaccelerator parameters are scaled by maintaining the total number of electrons incident on the converter target the same (10^{12}/pulse). The resultant parameters of the positron source are given in Table V. Using these source parameters, the overall transfer parameters have been evaluated for both the e⁻ and e⁺ case and are listed in Table VI.

Table V. Positron Source

Electron preinjector	100 MV - 0.4 A
Electron Linac	200 MeV - 0.16 A
Converter - electron on target	10^{12} /pulse
Positron Linac	800 MeV
Repetition rate	10 Hz
Positron/Electron ratio (.04/GeV)	.008
Positron Linac - 85% 'bite'	0.8
μ (positron/electron)	0.004
Positron current	0.64 mA
$E_x = E_y$ (≤ 85%)	3.2×10^{-6} m-rad
Energy spread (≤ 85%) (+/-)	0.01

Table VI. Beam Transfer Parameters

	e⁻ multibunch	e⁻ single bunch	e⁺ multibunch
Preinjector	Microtron	Microtron	Linac
Energy (GeV)	0.15	0.15	0.2(e⁻)-0.8(e⁺)
Current (mA)	20	40	0.64
Pulse length (μsec)	1	0.003	1
Rep rate (Hz)	10	10	10 (30)
$E_x = E_y$(85%) (m-rad)	$1\ 10^{-7}$	$2\ 10^{-7}$	$3\ 10^{-6}$
(ΔE/E) (85%) (+/-)	$0.7\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-2}$
(Preinjector-Booster)	(25%)	(25%)	(12.5%)
Booster (E=6 GeV; C= 297.6 m; h= 315)			
Current (mA)	5	0.032	0.08
Part/beam	$3.1\ 10^{10}$ e⁻	$2.0\ 10^{8}$ e⁻	$5.0\ 10^{8}$ e⁺
Part/bucket	$1.0\ 10^{8}$ e⁻	$2.0\ 10^{8}$ e⁻	$1.6\ 10^{6}$ e⁺
Rep rate (Hz)	10	10	10 (30)
(Booster-Storage Ring)	(50%)	(50%)	(50%)
Storage Ring (E = 6 GeV; C= 952.5 m, h = 1008)			
Current (mA)	200	10	200
Part/beam	$3.9\ 10^{12}$	$2.0\ 10^{11}$	$3.9\ 10^{12}$
Part/bucket	$3.9\ 10^{9}$	$2.0\ 10^{11}$	$3.9\ 10^{9}$
Charging time (min.)	0.43	3.36	26.6(8.9)

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