Rapidly-Modulated Variable-Polarization Crossed-Undulator Source

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Abstract

Continuing the growth of insertion devices as synchrotron radiation sources, the needs of research teams in many disciplines now mandate the construction of rapidly-modulated variable-polarization crossed-undulators for polarization sensitive experiments. Such a source is being proposed for the Aladdin storage ring at SRC to provide arbitrary polarization, modulated at 10 Hz, with first harmonic tunable from 8-40 eV. An outline for an entire system's design is presented, including diagnostics, initial-phase beamline, and controls. This facility will immediately benefit the scientific community and impact implementation of similar devices at third-generation facilities like ALS (Advanced Light Source, LBL), and APS.

I. Introduction

As a result of increased demand from the scientific community, several wiggler and undulator sources have been proposed which will increase the flux of circularly polarized x-rays [1]. Except for the crossed-undulator [2,3], all other possibilities employ inherently slow mechanical motion to vary the polarization. Because it uses an electromagnetic modulator, the crossed-undulator offers rapid, variable-waveform modulation between selected polarization states [3].

More than just the source, an entire system is being designed. Also included are: the diagnostics for characterizing the radiation; an initial-phase beamline for research at 8-40 eV; and the requisite computer control and coordination of the source, beamline, and storage ring operation.

Implementation of the crossed-undulator at SRC is being supported by researchers from chemistry, life sciences, materials science, and physics. Additionally, it will be an important precursor of similar devices at third-generation synchrotrons as the ALS and APS where such sources will extend variable-polarization capability to higher photon energies.

II. Conceptual Design

The crossed-undulator design uses two planar undulator sections, each producing linearly polarized radiation, rotated with respect to one another by 90° about their common longitudinal axis, and variably-phased along the same axis, as illustrated in Fig. 1. Specifically, in the present case, the undulators have been oriented at ±45° on either side of the vertical plane through the longitudinal axis. This orientation: maximizes the vacuum chamber's horizontal aperture; produces "erect" linear polarizations which can be interchanged by rapid modulation; and is inherently symmetrical.

A. Discussion Concerning the Radiation

The phasing between the radiations from the two undulators is determined by the differential flight times of electrons and photons travelling between them. Simplistically assuming spacially harmonic fields, and given

γ = electron energy
$\lambda_{u,m}$ = undulator & modulator periods, respectively
$B_{u,m}$ = undulator & modulator magnetic fields, respectively
B_m = $B_m^{dc} + B_m^{ac}\sin\omega t$, sum of the bias & modulated parts
$K_{u,m}$ = undulator & modulator deflection parameters
= $93.4 \times B_{u,m}(T)\lambda_{u,m}(m)$
λ = $\lambda_u(1+½K_u^2)/2\gamma^2$, undulator radiation wavelength
z = longitudinal spacing between the undulators
z_m = (effective) longitudinal length of the modulator
= λ_m

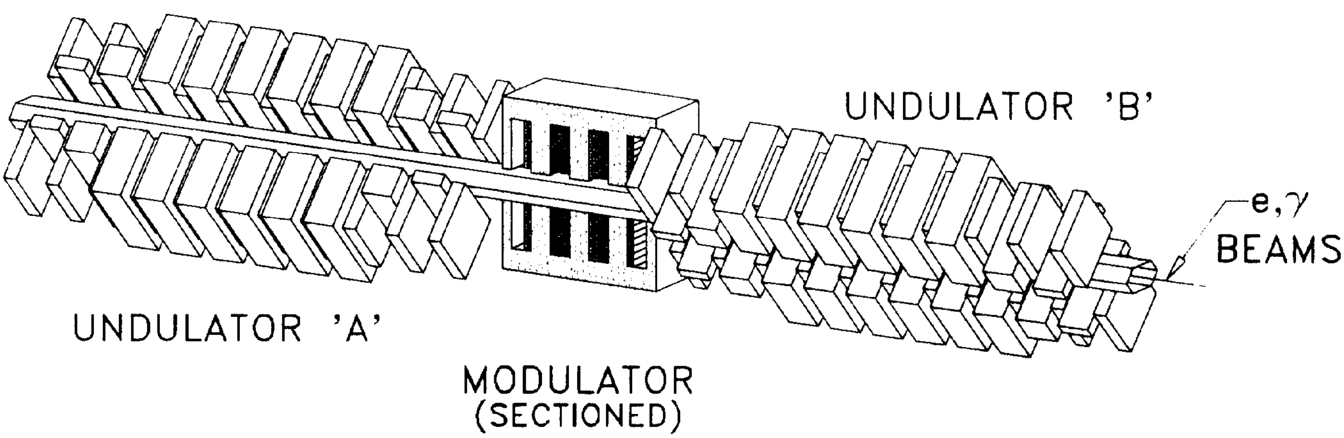

Figure 1: Conceptual illustration of the crossed-undulator source.

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the phasing, expressed in units of τ (= λ/c), becomes:

$$f = \frac{2z + z_m K_m^2}{2\lambda_u(1+\frac{1}{2}K_u^2)} = \frac{2z + 93.4^2 z_m^3 (B_m^{dc} + B_m^{ac}\sin\omega t)^2}{2\lambda_u(1+\frac{1}{2}K_u^2)} \cdot \quad (1)$$

Thus, for a given wavelength, λ, phasing can be varied both by changing the mechanical spacing between the undulators (z), and the excitation of the modulator (B_{dc} and B_{ac}).

When observed through a monochromator, the combined radiation is generally elliptically polarized. By varying the phasing the polarization of the combined radiation can be adjusted arbitrarily. In particular, it can be modulated between left and right circular polarizations (f = respective odd multiples of $\frac{1}{4}$) or between vertical (f = 1,2,3,...) and horizontal ($f = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$,...) linear polarizations.

The operation of the crossed-undulator is based on the interference effect, and requires a low-emittance electron beam for satisfactory performance for short wavelength radiation. Because of this, the upper limit will be about 100 eV on Aladdin. The spectral range can be extended to several hundred eV and higher with third-generation synchrotron radiation facilities, such as the ALS and APS.

B. Specifications

Table 1 summarizes requirements from the users of the crossed-undulator and for unimpaired operation of the Aladdin storage ring for all users.

Table 1: Functional Requirements

For Crossed-Undulator Users		
Spectral Range	8-40	eV
Total Phase Shift (ac+dc)	≤ 360	deg
Phase Modulation (ac)		
Rate	10	Hz
Amplitude	≥ 180	deg
For All Storage Ring Users		
Physical/Dynamic Aperture	No Reduction of:	
Injection (100 MeV)	Stored Current	
Full Energy (800 MeV)	Lifetime	
Vertical Beam Stability	Whole Ring, 800 MeV:	
Positioning	10	μm
Size	1.5	%

1. Undulator

Both sections will have independently adjustable gaps, and separate end-correctors and end-clamps. Table 2 shows other specifications generated by the requirements in Table 1. See §II.C.3 for further discussion concerning ring operation.

The undulator spacing, z, must accommodate the modulator and any diagnostics or steering elements for control of the electron beam. Although z must be kept to a minimum to maximize the radiation's degree of polarization, some variation of z will be incorporated. Both undulators, together, can be horizontally retracted from over the vacuum chamber, so as not to adversely affect low-energy injection into the ring.

Table 2: Preliminary Undulator Specifications

Magnetic Structure	Hybrid [4]	
Number of Periods, N	5/section	
Period Length, λ_u	10	cm
Geometry		
Orientations	±45	deg
Position @ Injection	Retracted	
Operating Ranges, Respectively		
Magnetic Gap, g	5 → 9	cm
Magnetic Field	0.38 → 0.11	T
K Value	3.5 → 1	
Photon Energy, 1st Harmonic	8.3 → 40	eV
Multipole Error Limits		
Dipole	8.54×10^{-6}	T·m
Quadrupole	0.04	T
Sextupole	0.3	T/m
Octupole	0.3	T/m^2
Maximum Gap for Retraction	16-19	cm
Vacuum Chamber Cross Section		
Horizontal	7	cm
Vertical	3	cm

2. Modulator

The main requirements for phase shift, frequency, and stability appear in Table 1. Details on this critical component can be found in a companion paper of these Proceedings [5].

C. Performance

By design, the undulators and modulator, will have negligible impact on storage ring operation. Thus, present operational ring parameters can be used for detailed calculations of the properties of the radiation.

1. Aladdin Operation

The ring routinely operates at 800 MeV with initial beam current of about 200 mA. Alternate operation also permits 1000 MeV at 80 mA, primarily for x-ray lithography.

Currently, there are several projects underway for the further improvement of the storage ring. These are primarily directed toward the continuing upgrade in user-oriented features such as the increased utility of Aladdin's long straight sections for insertion devices [6].

2. Polarization and Flux vs. Energy

Using present Aladdin parameters, crossed-undulator performances are as shown in Figs. 2 and 3 for several aperture sizes. For simplification the calculations use a Gaussian aperture-function of rms value $\sigma_\theta = \frac{1}{2}\sqrt{(\lambda/L)}$, where L = undulator length. Notes: the efficiency of the optical system is not accounted for in Fig. 3; also, the improvement programs mentioned above can only improve expected performance.

3. Interaction of Undulator and Storage Ring

Tables 1 and 2 summarized the principal requirements/specifications for undulator operation to non-adversely affect ring operation (for all users). The physical apertures are from

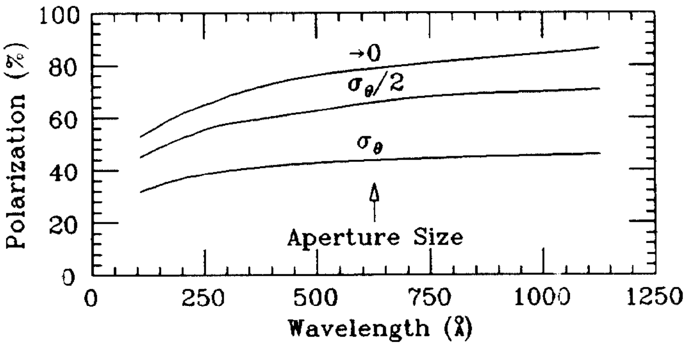

Figure 2: Degree of circular polarization versus wavelength

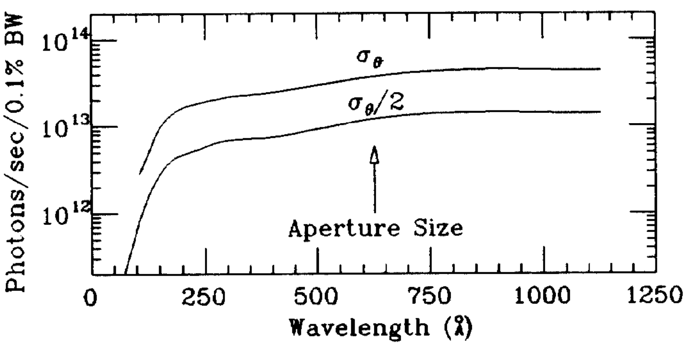

Figure 3: Photon flux versus wavelength.

scraper measurements made during injection, ramping, and full-energy operation. A stable (position and size) circulating beam gives rise to the limits specified on dipole and quadrupole field errors.

At (low energy) injection, acceptable dynamic aperture is easily achieved by simply retracting the undulators from over the beam/vacuum chamber. At full energy, linear lattice calculations on stability with SYNCH, and dynamic aperture calculations with PATRICIA, have been performed resulting in the higher (sextupole and octupole) multipole errors shown. Presently, extensive studies are underway to specify all tolerances including skew multipoles and misalignments.

III. System's Overview

The proposed system will result in a comprehensive facility for the production and utilization of variably-polarized radiation. Briefly, other aspects of the effort are as follows.

Undulator Radiation Diagnostics [7] Two different instruments are proposed to completely characterize the radiation between 10 and 40 eV. The first will measure the spatial dependence of the spectral flux, thus determining the phase-space volume of the radiation. The second is a polarimeter, with triple-reflector analyzer and quarter-wave devices.

Beamline Implementation [8] Taking advantage of the source collimation ($\Sigma_{x',y'} \leq 450$ µrad), distance (20 m), low power, and stability, the beamline is basically of the Wadsworth type [9], featuring: no entrance slit, no prefocusing optics, and a normal-incidence Pruett-Lien 1-m monochromator. These conditions result in a nearly stigmatic image at the exit slit which could be immediately useful.

Storage Ring Adaptations Onsite installation involves the design, construction, and installation of: the common undulator/modulator support structure; vacuum chamber section with localized pumping, clearing electrodes, and beam position monitors; and shielding of concrete and lead.

Control System Distinct functions of the control system include: undulator operation (independent gap control, retraction); modulator excitation (amplitude, waveform, frequency); longitudinal position (phase) control of one of the undulators; local orbit correction; local orbit steering; beamline control of beam energy, polarization, and position/angle. Given this complexity and that it must be transparent to other users of the ring pose a major challenge to the implementation of the control system.

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