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NSLS Prototype Small-Gap Undulator (PSGU)*

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Abstract

The NSLS Prototype Small-Gap Undulator (PSGU) will serve as a tool to study lifetime degradation and the onset of beam instabilities as the beam duct aperture is decreased. The device will consist of a variable-gap vacuum vessel and a permanent magnet undulator, with independent magnet-gap control. The vacuum vessel design attempts to minimize both residual gas pressures and beam impedances. The undulator will be 320 mm long and utilizes a pure-permanent-magnet structure with 6 blocks per 16 mm period. For a nominal operating aperture of 4 mm, PSGU will produce a peak brightness in the fundamental and third harmonic of 7×10^{16} and 1×10^{16} photons•sec^{-1}•mrad^{-2}•mm^{-2}•(0.1% BW)$^{-1}$ at photon energies of 2.5 keV and 7.5 keV, respectively.

I. INTRODUCTION

For storage rings used to produce synchrotron radiation, an important constraint on the operation of insertion devices is the minimum allowed magnet gap. A typical insertion device, wiggler or undulator, consists of a periodic magnetic structure, built surrounding the vacuum duct in which the stored beam circulates. The minimum magnet gap restricts the inner aperture of the vacuum duct. If this aperture is decreased, the performance of the storage ring may be degraded through a reduction of beam lifetime, or through the onset of beam instabilities, which may arise from the transverse coupling impedance. Beam lifetime depends on the beam duct physical aperture and on the residual gas pressure in the beam duct. If the limiting physical aperture in the storage ring is located in the insertion device, elastic scattering of beam particles on residual gas nuclei anywhere in the ring can result in particle loss at the insertion device. In addition, the residual gas pressure inside the insertion device influences other lifetime-determining mechanisms, such as bremsstrahlung on nuclei, scattering on electrons, and ion trapping. Photon-stimulated desorption and thermal desorption of gas molecules from the beam duct walls are promoted by synchrotron radiation. Thermal desorption is also promoted by component heating through longitudinal coupling impedances. The residual gas pressure inside the insertion device from these sources generally increases as the aperture is decreased, since a small aperture decreases the pumping conductance of the duct.

On the other hand, the performance of insertion devices is enhanced by decreasing the minimum magnet gap. The peak on-axis magnetic field is increased. For a tunable undulator, the tuning range is extended. Also for undulators, since the ratio of the gap to the undulator period exponentially influences the radiated output power, a reduced magnet gap permits a reduction of undulator period, to produce higher photon energies.

The NSLS Prototype Small-Gap Undulator (PSGU) will serve as a tool to study some of the effects which degrade storage ring performance as the beam duct aperture is decreased. It consists of a variable-gap vacuum vessel and a permanent-magnet, small-period undulator with independent magnet gap control. In the following sections, the design concept of the vacuum vessel, and some details related to it, will be presented, followed by a description of the permanent-magnet undulator, its design parameters, and anticipated performance.

II. VARIABLE - GAP VACUUM CHAMBER

A. Design Concept

The PSGU vacuum chamber concept is illustrated in Fig. 1, and borrows heavily from the design of the LBL/SSRL 54-Pole Wiggler [1]. The figure presents a cross section as seen along the stored-beam direction. Deep wells extend toward the beam from top and bottom wire-sealed flanges. Top and bottom bellows permit the distance between the wells to be increased and decreased by actuators tied between the flanges, outside the chamber. The bottoms of the wells, nearest the stored beam, are thinned, and the magnet beam arrays for the undulator are inserted into the wells, against the thinned sections. The outer vacuum wall, between the bellows, remains fixed in position, and contains ports for pumps, gauges, etc.

This concept holds a number of important features for a study of aperture effects, beyond the ability to vary the

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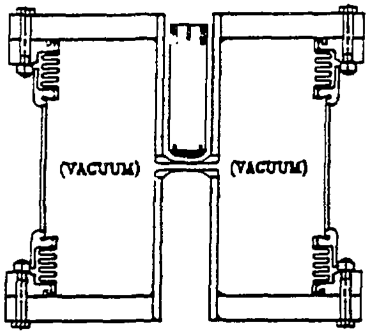

Figure 1. PSGU vacuum chamber concept.

aperture directly. Storage ring injection may require a larger aperture than that used for stored-beam operations, and this requirement is easily accommodated. A low residual gas pressure inside the device is important, as mentioned in the previous section. This implies provision for effective pumping of the minimum-aperture region, and for thorough bake out and conditioning of the vacuum vessel *in-situ*. The present concept permits removal of temperature-sensitive components, i.e., the permanent-magnet undulator, and the precision drive mechanisms, for *in-situ* bake-out of the vessel. In addition, a combination of pumping methods can be utilized to reduce the gas pressure in the minimum-aperture region.

B. Design Details

Figure 2 illustrates the layout of the X13 insertion straight of the NSLS X-Ray Ring, a 2.5 GeV electron storage ring designed for synchrotron radiation production. PSGU will occupy the center of the straight, while downstream, the NSLS Mini-Undulator [2] will be installed. Upstream, an insertable, water-cooled photon absorber will be used to block synchrotron radiation coming from the upstream bend magnet. When inserted to within 15 mm of the beam duct center, 110 W of radiation is absorbed. The shadow of the absorber then extends through PSGU and the Mini-Undulator, and finally ends beyond the downstream sector valve. This will help reduce the residual gas pressure due to photon-stimulated and thermal desorption in the straight. Electron beam position monitors are installed at the upstream and downstream ends of the straight, as well as in the upstream and downstream ends of the PSGU minimum-aperture region. Downstream of the straight section, out on the experimental floor, the X13 beamline, operated by the NSLS Beamline R&D Group, is equipped with photon beam position monitors and other diagnostics, and ties into a closed-loop feedback system for electron beam position stabilization.

The NSLS X-Ray Ring insertion straights are low β straights, with $\beta_x^* = 1.7$ m, $\beta_y^* = 0.35$ m at the straight center. The limiting vertical aperture in the ring is the standard extruded aluminum beam duct at $\beta_y$max, i.e., 42 mm at a β function of 27.5 m. The minimum-aperture region in PSGU extends $\pm$ 200 mm of the straight center, which implies a small-gap limit of 5.5 mm, without reducing the vertical acceptance. The PSGU vacuum chamber is designed to open to a 20 mm aperture and to close essentially to zero. Our nominal design goal is operation at an aperture of 4 mm, although the practical limit will be found experimentally.

As mentioned in the Introduction, transverse and longitudinal coupling impedances contribute to beam instabilities and component heating, respectively. The worst-case resistive-wall power deposition is estimated at 3 W for a 2 mm aperture. This results in an acceptable maximum temperature rise of about 5°C. Instabilities may be significant above 100 mA stored beam current for the same 2 mm aperture, but at the nominal 4 mm value, the beam should be stable to 250 mA, the maximum current presently anticipated. Transitions in and out of the minimum-aperture region are also important for the impedances they can generate. Reduction of impedances requires a smooth continuous conductive path for beam image currents throughout the straight section. We plan to use flexible metal sheets to make the transitions between the minimum-aperture region and the regions upstream and downstream. In addition, a program to experimentally measure longitudinal and transverse coupling impedances of proposed designs, using the methods repo.ted by Walling et al. [3], is presently underway.

III. PSGU MAGNET

The parameters for the PSGU magnet are summarized in Table 1. It uses the high-performance 6-block-per-period version of the Halbach pure-permanent-magnet (PPM) design as developed by Rocketdyne [4]. This design makes possible

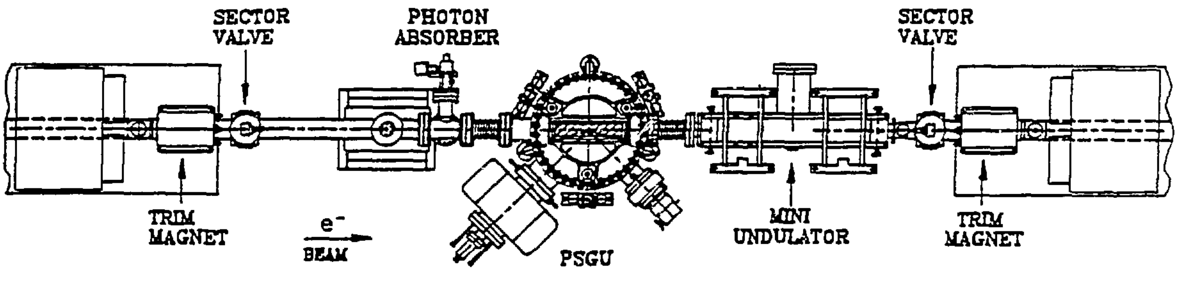

Figure 2. Layout of X13 insertion straight section.

Table 1
PSGU Magnet Parameters

Construction	*6-Block PPM*
Period, λ_u	*16mm*
Length, L	*320mm*
Magnet Gap Range, g	*18 mm - 4 mm*
Deflection Parameter Range, K	*0.1 - 1.5*
Peak On-Axis Field	*64 mT - 1.0 T*
Magnet Alloy *Remanence, Br*	*NdFeB* *1.2 T*
@ Nominal Gap *Chamber Aperture* *Magnet Gap* *Peak On-Axis Field* *Deflection Parameter, K*	 *4.0 mm* *6.0 mm* *0.68 T* *1.0*

peak field values comparable to the Halbach hybrid design [5], but retains the benefits of an "iron-free" design, namely the applicability of superposition. Figure 3 presents a schematic view of the construction. To minimize field errors, several stages of characterization, followed by simulated annealing, are performed. Individual blocks are first characterized and sorted into triplet modules of equal strength. For PSGU, the blocks in a triplet are bonded together and post-machined to precise dimensions. The triplets are then characterized and ordered to simultaneously minimize normal and skew multi-pole errors and optimize performance. Finally, the partially-assembled magnet beams are mapped and end blocks selected to minimize beam steering and displacement.

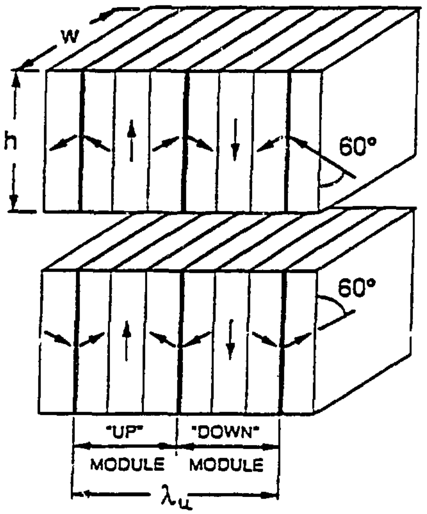

Figure 3. 6-block PPM construction.

The anticipated performance of PSGU at the nominal magnet gap of 6 mm is summarized in Table 2, for the fundamental and 3rd harmonic. These values include the emittance of the NSLS X-Ray Ring. The photon energy of the fundamental was chosen to be the sulfur K absorption edge, in anticipation of possible interest in S microscopy or near-edge spectroscopy. In terms of flux and brightness at this energy, PSGU will provide at least comparable performance to the best existing sources.

Table 2
*PSGU Magnet Performance**

@ Nominal Gap, g = 6.0 mm		
	Harmonic	
	Fundamental	3rd
λ_{out}	4.9Å	1.6Å
$h\nu_{out}$	2.5keV	7.5keV
Peak Brightness†	$7x10^{16}$	$1x10^{16}$
Central Cone Flux‡	$4x10^{14}$	$7x10^{13}$
Total Radiated Power	150 W	
Tuning Range		
Gap Range, g	18 mm - 4 mm	
λ_{out}	3.3Å-6.9Å	1.1Å-2.3Å
$h\nu_{out}$	3.8keV-1.8keV	11.3keV-5.4 keV

*NSLS X-Ray Ring, E=2.53 GeV, I=250 mA.
†Photons•sec^{-1}•$mrad^{-2}$•mm^{-2}•$(0.1\% BW)^{-1}$.
‡Photons•sec^{-1}•$(0.1\% BW)^{-1}$.

IV. REFERENCES

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