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Performance and Upgrades of the NSLS Storage Rings and Photon Sources*

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Abstract

The usefulness of synchrotron radiation sources is not only determined by current, energy and magnetic field but also orbit stability and lifetime. The status and developments at NSLS in storage ring performance are discussed. Efforts at NSLS to look toward the future in source development are presented. In particular, small gap undulator development and studies toward development of UV Free Electron Laser at the Accelerator Test Facility are described.

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Introduction

Accelerator based photon sources for research in the biological, chemical and materials sciences have come a long way from the parasitic use of synchrotrons designed for stationary target high energy physics. Today there are numerous dedicated storage ring based sources operating world wide and many more under construction. Among the important features of storage ring design, which is a continuously evolving field, are: position stability and 'constant' intensity (long electron beam lifetime). Efforts to improve these aspects, as well as overall storage ring operations and special source development have been underway at the National Synchrotron Light Source for some time. In the following paragraphs progress in these areas as well as developments in a small superconducting storage ring for x-ray lithography and an accelerator test facility are discussed.

Orbit Stabilization

Stability of the electron orbit is essential for the utilization of a low emittance storage ring as a high brightness radiation source. For an individual user, the required orbit stability can be achieved by a local bump feedback system. However, to install local bump feedback systems for every beamline is both costly and impractical. The coupling between different local bumps may introduce instability, and there may not be enough space for the large number of trim coils required. At the NSLS, we have developed a feedback system stabilizing the global orbit all around the ring, based upon harmonic analysis of the orbit movements and correcting magnetic fields [1]. The harmonic feedback system corrects the Fourier components of the orbit nearest to the betatron tune, an approach which yields an orbit whose stability is sufficient for most experiments. The needs of the experiments requiring the tightest orbit tolerances can still be dealt with by additional local orbit feedback systems.

A prototype global feedback system was commissioned on the VUV-ring, and has been successfully used for several years to stabilize the vertical orbit, reducing orbit movements by more than a factor of three everywhere and by a factor of ten at many source locations.

At present, horizontal and vertical global orbit feedback systems are in operation on the X-Ray ring, reducing orbit movements by at least a factor of five everywhere and by a factor of ten at many source locations. This can be seen graphically in figure 1. The top panel is the measured displacement of the electron beam at one pick up electrode (PUE) used for beam position measurement. The panel shows the effects of the feedback system as it is sequentially

cycled on and off. The bottom panel is a plot of the beam position at all the PUE's around the X-ray ring with the feedback on and off. New global orbit feedback systems will be installed on the VUV-ring to stabilize both the horizontal and vertical orbits by winter 1992.

Lifetime

The electron beam lifetime in the VUV ring is limited by the loss of electrons due to intrabunch (Touschek) scattering. The loss rate due to the Touschek effect is proportional to the electron bunch density. Hence, in order to increase the beam lifetime we must reduce the bunch density. On the other hand, a key design feature of the VUV ring is the achievement of high brightness of the photon sources by having an electron beam with small transverse beam dimensions. Therefore, to increase the beam lifetime without reducing the source brightness, we have installed a fourth harmonic RF cavity in the VUV ring to increase the bunch length. At present, the cavity is operated passively, without external RF power, and results in a doubling of the bunch length and the lifetime of the beam at high current [2]. This is seen easily in figure 2 where lifetime as a function of stored current is plotted with and without the fourth harmonic cavity.

Special Sources

The ability to place special magnetic devices in the otherwise field free straight sections of the NSLS and most modern synchrotron radiation storage rings greatly enhances important photon source parameters. The relevant parameters of the devices that are installed and operational at NSLS are given in Table 1. To further enhance these capabilities a device, the Prototype Small Gap Undulator (PSGU), is being constructed to test the lower limit of possible magnet gap at the NSLS X-Ray ring.

The betatron functions at the center of the X-Ray ring straight sections are quite small, $\beta_x = 1.5\text{m}$, $\beta_y = 0.33\text{m}$, resulting in very small transverse electron beam dimensions, but somewhat larger angular spread. Some advantages of low- β insertions are: the effect of the wiggler magnetic fields on the lattice are minimized, the brightness is optimized for short high-field wigglers, and the low vertical beta function allows the development of very small gap devices at the insertion center. The PSGU project at the NSLS will provide the variable gap vacuum chamber and magnet to study the impact of these devices on storage ring operation.

Our goal in the PSGU project is to achieve operation of a 16mm period undulator with a 4mm vertical beam aperture, and a 6mm magnet gap [3]. If successful, this small gap

undulator would provide a very bright source of x-rays at the fundamental, 2.5 KeV, and the third harmonic, 7.5 KeV. Moreover, we are installing sufficient diagnostics to enable a systematic study of the limitation on the chamber aperture, and the results of this experiment should be of importance in the design of future synchrotron radiation sources.

Accelerator Test Facility

The Accelerator Test Facility (ATF) is being constructed under the auspices of the Center for Accelerator Physics (CAP) at Brookhaven, and is a collaboration between the NSLS, Physics and Instrumentation departments at the laboratory. The centerpiece of the ATF is a high brightness photo cathode electron gun followed by a 50 MeV linac [4]. Users of the ATF will carry out experiments aimed at the development of advanced acceleration methods and free electron lasers (FEL).

The NSLS is very interested in the development of FEL sources and is actively pursuing the design of a UV-FEL to operate from the near UV down to 750 Å. The design is based upon a subharmonically seeded FEL amplifier. In this device, a seed laser at 3000 Å is used to produce an energy modulation in an initial short wiggler resonant at 3000 Å. Using a dispersion section, this energy modulation is converted to spatial bunching. The bunched electron beam, which is rich in harmonic components at 3000 Å, 1500 Å, 1000 Å, 750 Å..., is then passed through a second wiggler resonant at, for example, 1000 Å. In this case, there is coherent emission at 1000 Å, then exponential growth of this radiation, and finally a tapered section is used to reach a peak power of 200 MW at 1000 Å.

Superconducting X-Ray Lithography Source

The SXLS project underway at the NSLS is developing a 700 MeV compact storage ring of circumference 8.5m, utilizing superconducting dipoles with a field of 3.87T to produce 10 Å x-rays for proximity printing lithography. This project is funded by the Defense Advanced Research Projects Agency (DARPA), and has as its goal the transfer of the SXLS machine construction technology to US industry. The Grumman Aerospace Corporation and General Dynamics have been selected as the industrial collaborators.

In the first phase of this project, a machine of the same geometry as the final machine was constructed with low field (1.1T) iron dipole magnets, having the same bending radius, 0.60m, as the superconducting magnets. This Phase I ring has been successfully operated with over 1 Ampere of circulating current, confirming many elements of the storage ring design [5].

The superconducting magnets for the Phase II machine are presently under construction by General Dynamics.

Summary

With the evolution of beamlines and x-ray optics, there has been a complementary evolution of storage ring performance. The NSLS is continually developing new technologies to improve storage ring performance and to push for new accelerator based photon sources. The above gives some glimpse of the status of these efforts.

References

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Figure Captions:

- Figure 1** **Top panel:** displacement at one electron beam position monitor (pick up electrode [PUE]) as the real time global orbit feedback is cycled on and off.
- Bottom panel:** Measured displacements at PUE's distributed around the x-ray ring with the feedback on (--- dashed line) and off (— solid line). Arrows indicate measurement points for the feed back signal.
- Figure 2** Comparison of lifetime with and without the 4th harmonic cavity in the VUV ring. Lifetime is plotted as a function of stored electron beam current.

TABLE I

Energy Parameters for the NSLS Insertion Devices (January 1991)						
Parameters	U5U	U13TOK	X1	X13	X17	X21/X25
Magnetic Field - $B_{\max}$	0.46-0.01 T	0.72-0.05 T	0.31-0.03 T	0.31-0.03 T	5 poles @ 5.2 T 2 poles @ 2.6 T	1.1 T
Number of Poles - N	55	44	69	20	7	27
Period Length - λ	7.5 cm	10 cm	8 cm	8 cm	17.4 cm	12 cm
Wiggler Characteristic Energy - E_c	--	265 eV	--	--	22.2 keV (for 5.2T poles)	4.57 keV
Energy Range (Undulator Fund.)	11.3-70 eV	2.2-50 eV	0.19-0.73 keV	0.19-0.73 keV	10-100 keV	4-30 keV
Deflection Parameter Range -K	3.2-0.08	6.7-0.4	2.3-0.2	2.3-0.2	84	12.3
Gap Range	3.4-12.0cm	3.35-12.0 cm	3.3-9.8 cm	3.3-9.8 cm	3.2 cm (fixed)	2.4-12 cm

VUV Ring Energy = 745 MeV; X-ray Ring Energy = 2.5 GeV

VUV Ring Lifetime Comparison

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