Review of Scientific Instruments

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Cite as: Review of Scientific Instruments **60**, 1403 (1989); https://doi.org/10.1063/1.1141003
Published Online: 19 August 1998

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Overview of the advanced photon source (invited)

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(Presented on 29 August 1988)

The Advanced Photon Source planned for construction at Argonne National Laboratory is based on a low-emittance storage-ring operated at 7 GeV and capable of providing tunable undulator radiation from 4 to 40 keV (using the first and the third harmonics). A technical description of the accelerator facility and the storage ring is presented in this overview, along with a brief summary of the characteristics of radiation that will be available from the insertion devices. Various plans for user access to this national user facility are also given.

INTRODUCTION

Over the past two decades synchrotron radiation has become an increasingly important tool for studying the geometric and electronic structure of materials. In addition, development work to date indicates potential commercial application in such diverse areas as the manufacture of semiconductor memories and the diagnosis of coronary heart disease. Synchrotron research was first carried out on a generation of storage rings built for studying electron-positron collisions. The pioneering efforts at such facilities as the Stanford Synchrotron Radiation Laboratory provided the experience necessary to design storage rings with electron beam properties much better suited to providing synchrotron radiation. As a result, second generation machines such as those at the Brookhaven National Synchrotron Light Source and at the Wisconsin Synchrotron Radiation Center are now in full operation and under very heavy demand. Now, as a consequence of new technology, a third generation of machines is at hand. Third generation machines, such as the Advanced Light Source at Berkeley Laboratory and the Advanced Photon Source (APS) at Argonne National Laboratory are specially designed to implement new periodic magnet devices called undulators to perturb the charged particle beams in such a way as to produce a beam with considerably increased spatial and temporal coherence. In this article, we will review the current design for the Argonne APS machine and its associated undulator magnets, as well as briefly discuss the issues relevant to the scientific use of the facility when it becomes operational in 1995.

I. APS STORAGE RING

A. Lattice

The 1104-m circumferences of the APS storage ring is divided into 40 sectors. Each sector contains 3.06-m bending magnets and a long dispersion-free straight section designed to accommodate a 5.2-m insertion device. Figure 1 shows the vertical and horizontal lattice functions and the dispersion functions for one sector. Two sites of triplet quadrupoles in the dispersion-free region provide versatility in adjusting the beam size in the insertion device.

When the quadrupoles are adjusted with equal lattice functions in all sectors the horizontal and vertical tunes are $\nu_x = 35.2$ and $\nu_y = 14.3$, respectively. The natural emittance for this condition is 8.4×10^{-9} m rad.

B. Chromaticity corrections and sextupole correction

Three sextupoles, located in the dispersion straight sections, are used to correct the chromaticity. The nonlinear effects of these sextupoles are largely canceled by four sextupoles in the dispersion-free regions. These corrections sextupoles, which do not affect the chromaticity, reduce the amplitude dependent tune shifts and restore the dynamic aperture. They also help to reduce instabilities caused by quadrupole alignment and magnet field tolerances.

C. Circulating bunch distribution and current

The energy loss of the circulating positrons due to radiation is 5.45 MeV per turn. The energy loss per turn is restored by a 9.5-MV rf system which occupies three of the dispersion-free straight sections. The system operates at 352 MHz which is the 1296th harmonic of the revolution frequency. Under normal operating conditions, the positrons are distributed uniformly in a relatively small number of rf buckets to produce a total current in excess of 100 mA. Each bucket can accommodate up to 5 mA of beam.

D. Injection and fill time

The injection system for the ring consists of a 250-meV electron linac, a tungsten electron-to-positron converter, a 450-meV positron linac, a 450-meV positron accumulator, and 450-meV to 7-GeV injector synchrotron.

The synchrotron operates at 2-Hz repetition rate. The accumulator ring collects the positrons from the 450-meV

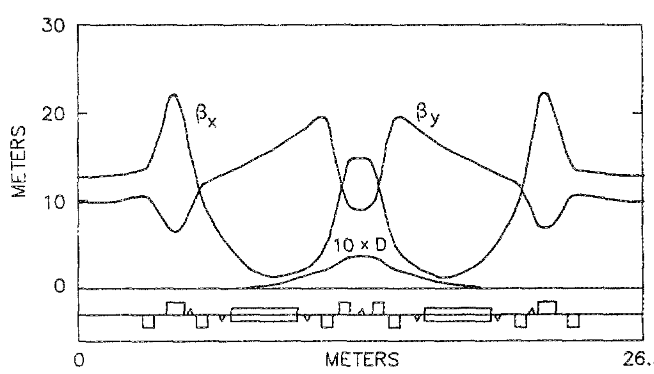

FIG. 1. Storage-ring lattice functions, β_x, β_y and dispersion function, D, for one cell of the APS.

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linac during a 0.5-s cycle time of the synchrotron. Once each cycle, the positrons are transferred from the accumulator ring into a single bucket of the 352-MHz rf system of the synchrotron. At 7-GeV the bunch is extracted from the synchrotron and injected into a designated rf bucket in the storage ring. The time required to fill the storage ring to 100 mA is less than 1 min.

II. INSERTION DEVICES ON THE APS

The present design permits the operation of as many as 34 insertion devices. In addition, there will be 35 bending magnet sources delivering white radiation with a critical energy of 19.5 keV. A generic undulator with a magnetic period of 3.1 cm provides wide tunability of x rays from 4 to 14 keV in the first harmonic by varying the gap because of the choice of 7-GeV for the storage ring operation. Concurrently, the third harmonic from this device will be tunable from 12 to 42 keV.

The low emittance of the positron beam provides typical on-axis brilliance for the fundamental radiation from 10^{18} to 10^{19} photons/s/0.1%/BW/mrad^2/mm^2. The opening angle of the undulator radiation will be as small as 10 to 20 μrad.

There will be experiments needing wiggler radiation from the APS. Even with permanent magnet technology, the critical energy of the wiggler radiation can be as high as 60 keV.

There are plans to build more specialized insertion devices capable of delivering radiation with variable polarization. For example, a wiggler generating deformed helicoidial positron trajectory will produce radiation with polarization of variable ellipticity.

The time structure of the APS will provide 100 ps bursts of x rays from each bunch which will be useful in many time evolution studies proposed for this machine. A detailed account on all the above characteristics of the radiation has been described elsewhere.[1,2,3]

During the past year, a 3.3-cm-period APS prototype undulator was designed and constructed. This hybrid device with 123 poles consists of Nd-Fe-B magnets. The tests for its performance were carried out at the Cornell Electron Storage Ring (CESR) and a detailed report is available in these proceedings.[4] In these tests, the CESR lattice was operated in a low-emittance mode and it was found that the measured brilliance of the source was close to that predicted through a detailed modeling. A detailed account of the emittance measurement using the x rays from the undulator has been given in the report. In Fig. 2, the brilliance of this undulator source has been compared with that of possible APS insertion devices and some of the operating sources.

The prototype undulator was operated with a minimum gap of 1.5 cm dictated by the aperture requirements on CESR. This fact coupled with the storage-ring energy of 5.43 GeV provided a limited tunability of the first-harmonic radiation from about 4 to 8 keV, achieved through a gap variation. It is clear that the choice of 7 GeV for the APS should provide considerably larger tunability range. The spectral properties of this device were measured in detail and one could observe up to the seventh harmonic of radiation with a

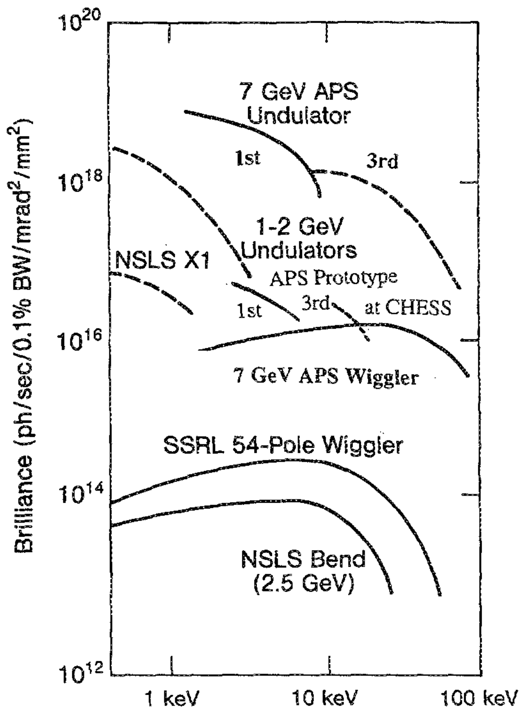

FIG. 2. Brilliance as a function of radiation energy for a 3.3-cm-period undulator on the APS; the brilliance of other sources is presented for comparison.

K value of 1.4 (at a gap of 1.5 cm).

The total power delivered by the undulator was as high as 456 W with a peak power density of 23 kW/mrad.[2] A unique solution for handling this power without loss of source brilliance was developed. In this procedure, liquid gallium was pumped through channels drilled in silicon optics which provided extremely efficient cooling.[5]

While many interesting scientific investigations were performed using this APS prototype undulator, the measurement of a diffraction pattern from a small organic molecule (an indole alkaloid) and an enzyme (lysozyme) should be considered most spectacular.[6] The diffraction patterns of great clarity from these systems were recorded in less than a nanosecond. This opens new possibilities to investigate evolution of dynamic processes in materials, chemical, and biological sciences in the future. For example, such studies using a single bunch of photons from the APS should provide a time window of less than 100 ps.

III. USER ACCESS TO APS

The APS is a national user facility, and, hence, great importance is given to facilitate user access to and interaction with the facility. Towards this goal many committees and subcommittees involving the user community have worked closely with the APS staff and provided many suggestions and plans to make APS a useful user facility. Two major user meetings were held each involving over 300 users.[7,8] These meetings provided an opportunity for the users to see the progress of the APS design and plans, in addition to developing plans to form teams to build various beamline facilities at the APS. Over the next few years, the users will form collaborative teams which will design beamlines and experimental facilities needed to carry out their research at the APS.

Guidelines are now being developed in consultation with the APS User Organization for these teams to operate effectively. Currently there are many forms of collaborative teams that are being considered. For example, a collaborative team can represent a third party national/regional facility. Such a team will obtain full funding from an agency for the construction of the insertion devices, beamlines and other experimental facilities. The team will monitor the beam time needs of all the members of the community. Such a plan has now been proposed for a biomedical complex to be funded by the Office of Health and Environmental Research (OHER) for the Department of Energy. In another class of collaborative teams, the representatives will be from the universities, national laboratories, or industries. In addition, plans to form teams representing venture synchrotron companies, providing service to general industries or other small/infrequent users for a fee, are also being studied.

In addition, independent users will have access to all the beamlines at the APS. For this purpose, the collaborative teams will furnish a certain fraction of the beam time. This fraction of beam time available on each of the beamlines will depend on the agreement made by the collaborative team responsible for that particular beamline, the agreement being determined by various requirements related to the nature of the team. Indeed, the facility will support users performing various types of research such as open, proprietary, and classified.

The selection of a collaborative team will be performed by a Program Advisory Committee to the APS. The criteria for the selection of a proposal will be based on scientific content of their proposal, research competence of the team members, management plan, and uniqueness.

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[7]*Proceedings of the First Users Meeting of the Advanced Photon Source*, Argonne National Laboratory, Nov. 13–14, 1987, ANL Report, ANL/APS-CP-1 (Feb. 1988).

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