THE ADVANCED PHOTON SOURCE LOW-ENERGY UNDULATOR TEST LINE

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Abstract

There are a number of fully commissioned 3rd-generation synchrotron light sources in the world today. So far they have met the demanding requirements of the user community; however, there is always a desire to go beyond what is presently available or even desirable. The Advanced Photon Source (APS) Low-Energy Undulator Test Line (LEUTL) was conceived to address the advancement of synchrotron light sources. The LEUTL uses the existing APS linac and a low-emittance electron gun, and by means of measurements of the beam and generated light, will test new and innovative undulators and push the technology and physics of single-pass, coherent light sources. The design and status of the LEUTL will be described along with its immediate capabilities and those planned for the future.

1 INTRODUCTION

The APS linac is capable of accelerating electrons to more than 700 MeV. Coupled with a high-brightness, low-emittance electron source, it can also be used to explore areas beyond those for which it was originally intended, areas important to the future of synchrotron radiation sources and facilities.

The LEUTL was conceived and designed to examine just such topics. It consists of a high-brightness, thermionic rf gun, the APS linac, and additional beamlines directing the accelerated electron beam into a special-purpose enclosure with attached optical end station building. The LEUTL's purpose is twofold: the first is to fully characterize innovative, future generation undulators, some which may prove difficult or impossible to measure by traditional techniques such as very long small-gap undulators, superconducting undulators, and helical undulators; and the second is to act as a test line to investigate generation of coherent radiation at wavelengths down to a few tens of nanometers.

2 DESCRIPTION

Four modifications to the APS facility are required to make the LEUTL fully operational:

- Installation of a high-brightness thermionic rf gun.
- Addition of beamlines required to bypass both the positron accumulator ring (PAR) and the booster synchrotron (booster).
- Extension of the booster vault into the new LEUTL beamline enclosure and end station building.
- Construction of the undulator test line.

2.1 RF Gun

At the head of the APS linac a high-brightness thermionic rf gun with alpha magnet bunch compression [1] has been installed and is presently being commissioned (Figure 1). Table 1 lists the expected gun and transport system performance. This gun produces an electron beam of sufficient quality for most of the initial planned testing and experiments; however, additional high-brightness beam concepts are being pursued both in collaboration [2] and through an in-house effort using a laboratory-directed research and development award.

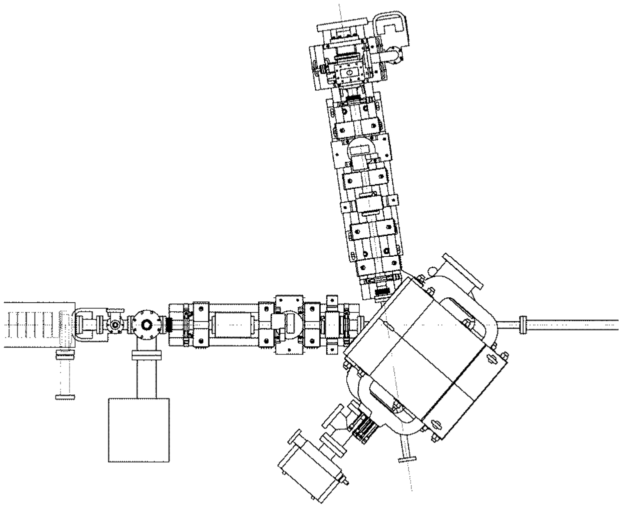

Figure 1: RF gun and transport system.

Table 1: Expected Gun Performance

Energy	3 MeV
Peak current	150 A
Normalized emittance	$5\pi \bullet$ mm-mrad
Energy spread	1%

2.2 Linac Diagnostics and Transfer Lines

The APS linac is reasonably well instrumented; however, additional beam diagnostics have been added to provide enhanced characterization of the high-brightness electron beam. In particular, optical transition radiation (OTR) screens have been installed at strategic locations. The light generated from these screens will be transported either to radiation-resistant hutches or outside the linac enclosure. Sensitive high-resolution cameras have been procured for detection of the beam profile signals and a 0.6-ps-resolution fast streak camera will be used for bunch length measurement.

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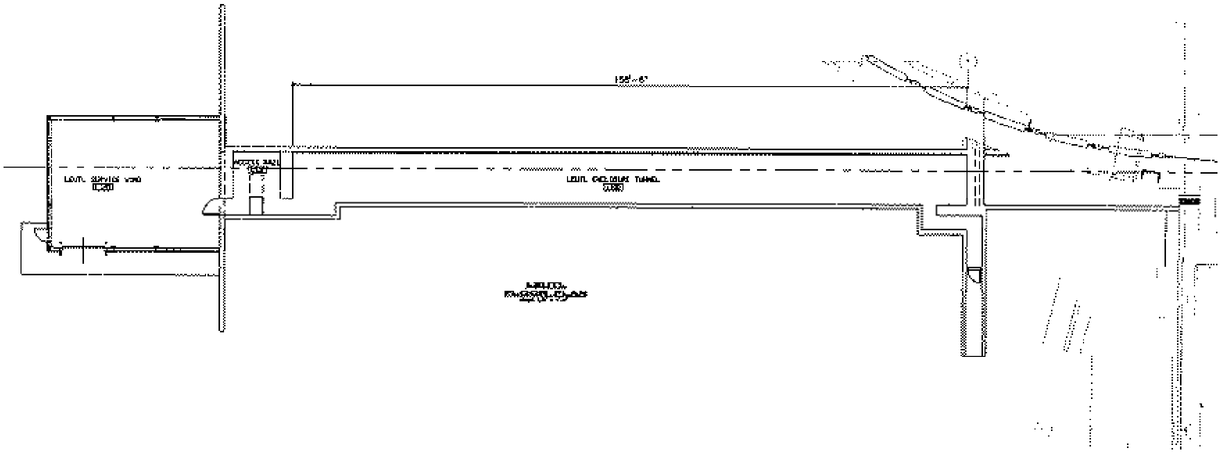

Figure 2: The LEUTL enclosure and end station building.

Following acceleration, two additional sections of beamline are required to guide the beam past both the PAR and booster and into the LEUTL main enclosure. The PAR bypass line is equipped with OTR screens in a 10-m region clear of magnetic elements. This will permit a very accurate characterization of the beam quality after passage through the linac. This OTR screen system will be capable of determining a normalized emittance of $\varepsilon_n = 10\pi \cdot$ mm-mrad to ≈ 6% and $\varepsilon_n = 1\pi \cdot$ mm-mrad to ≈ 20%.

The booster bypass line is approximately 55 m in length. Over 40 m of this length a gentle elevation change of 1 m will be made primarily to avoid interferences with the booster. Theory [3][4] shows that the resultant growth in emittance caused by this bending is negligible.

2.3 Building

Figure 2 shows a layout of the LEUTL building. It consists of two parts: an earth berm covered concrete enclosure for the electron beamline, undulator, and beam dump; and an end station building which houses technical components and the diagnostics for characterizing the light produced by the undulators under test. The beamline enclosure has nearly 50 m of available length and is 12 ft wide. Provisions have been made to house two separate beamlines, one straight ahead relative to the APS linac and the second offset by 5 ft horizontally. The end station building has approximately 1200 square feet of available floor space and can be occupied while beam is being delivered to the LEUTL enclosure.

3 UNDULATOR TESTING

3.1 Beam-Based

The LEUTL will offer a unique method for performing magnetic measurement of undulators. Measurements will be made by passing the electron beam through the undulator while very precisely measuring the beam position and angle. Using this information, a very accurate measure of the first and second field integrals will be made. The measurement will be further enhanced by employing a magnetic telescope arrangement proposed by M. Borland. This system can provide a point-to-point magnification of -13.5 and a similar magnification of 8.8 m/rad in parallel-to-point mode. Further enhancement will be achieved by averaging the position signal over many shots. As an example, consider measurement of the first and second field integrals

$$\int_1 = \frac{\delta x(B\rho)}{M_\theta A} \qquad \int_2 = \frac{\delta x(B\rho)}{M_x A}, \qquad (1)$$

where δx is the single-pass measurement accuracy, M_θ and M_x are the parallel-to-point (in units of m/rad) and point-to-point magnifications, respectively, and A is the improvement due to averaging. Assume

$$\begin{aligned} &B\rho = 2\ T \cdot m; \quad \delta x = 10\,\mu m; \\ &M_\theta A\left[m/rad\right] = M_x A = 100\ , \end{aligned} \qquad (2)$$

then

$$\int_1 = 0.2\,G \cdot cm \qquad \int_2 = 20\,G \cdot cm^2. \qquad (3)$$

For comparison, 2.5-m-long APS type-A undulators are measured using a traditional magnetic measurement system [5] with repeatability to < 1 G-cm and absolute accuracy of 10 G-cm in the first field integral, and with repeatability to < 100 G-cm^2 and absolute accuracy of 1000 G-cm^2 in the second field integral.

3.2 Light Output

An alternative to beam-based measurements in determining the overall magnetic quality is to use the light generated by the beam/undulator system. This is made possible by the high quality (small emittance and energy spread) of the electron beam. A simulation using various different scenarios was performed by R. Dejus to check the capability of this method [6]. Figure 3 shows the output at the 9th harmonic of the emitted radiation for a typical APS type-A undulator and a beam of 650 MeV. Most relevant is the comparison between curves 2a and 4a which show the degradation in the amplitude of the 9th harmonic in the presence of typical undulator errors.

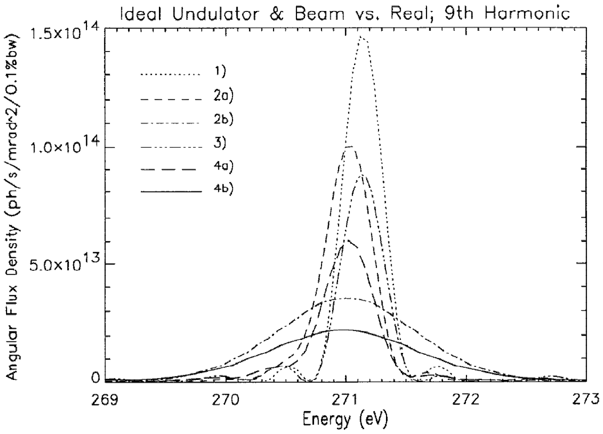

Figure 3: 1) Ideal beam, ideal undulator; 2a) Ideal undulator, beam with emittance (no energy spread); 2b) Ideal undulator, real beam ($\Delta E/E = 0.1\%$); 3) Real undulator, ideal beam; 4a) Real undulator, beam with emittance (no energy spread); 4b) Real undulator, real beam ($\Delta E/E = 0.1\%$).

4 COHERENT LIGHT POSSIBILITIES

The possibility of achieving coherent light generation in a single pass of an undulator at wavelengths less than 100 nm exists with the LEUTL system. Studies have been carried out to determine the requirements of an undulator system used to study the self-amplified spontaneous emission (SASE) process [7]. These studies were based on a conservative estimate of the beam quality from the thermionic rf gun source. The undulator design was optimized with an initial wavelength goal of 120 nm using a 400-MeV electron beam. A simple planar undulator with separated-function external focusing and a fixed gap was chosen. An undulator length sufficient to reach saturation in a single pass would be built up of 2.5-m-long cells with 2 m of undulator and 0.5 m available for external focusing plus diagnostics. The results of calculations and simulations indicate a gain length of 1.5 m with saturation predicted to occur after passage through 15 undulator cells. The principle parameters for this mode of operation are shown in Table 2.

Table 2: Optimized FEL Undulator Design

Wavelength	120 nm
Electron energy	400 MeV
Normalized emittance	5 π mm-mrad
Energy spread	0.1%
Peak current	150 A
Undulator period	27 mm
Magnetic field	1.2 T
Undulator gap	5 mm (fixed)
Focusing	separated quadrupoles
Gain length	1.5 m
Undulator length	15 × 2.5 m

The LEUTL beam energy can be raised to 700 MeV with a commensurate reduction in the output wavelength of the undulator. This and the use of a photocathode rf gun electron source were both considered during the optimization process of the undulator. At the higher energy the system should be capable of achieving saturation down to a wavelength of 40 nm.

5 PRESENT STATUS AND SCHEDULE

The present status of the LEUTL project is as follows. The thermionic rf gun and alpha magnet system is installed with beam produced and delivered straight ahead into a Faraday cup. Further commissioning of the gun awaits completion of a “beam gate” kicker magnet and rework of the rf waveguide, both of which should be ready by July 1997. All primary in-vacuum additional diagnostics hardware has been installed in the linac with some optical transport still remaining to be complete. The PAR bypass will be installed and ready for use by August 1997, and the booster bypass and beamline into the LEUTL enclosure will be completed by early winter of 1997. The LEUTL building will be ready for beneficial occupancy by early summer of 1997. Already designed is a prototypical undulator section for testing single pass SASE-mode operation. This should be available for installation in the fall of 1997. First measurements of undulator properties should begin early in 1998. Upgrade to a high-brightness gun is planned for sometime late in 1998.

4 ACKNOWLEDGMENTS

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REFERENCES

[1] M. Borland, “Cavity Design and Beam Simulation for the APS RF Gun,” *APS Light Source Note* **LS-186**, Dec. 1991.

[2] J. Schmerge et al. “SLAC RF Photocathode Gun Test Facility,” *SPIE Lase ‘97 - Free-Electron Laser Challenges Conf.*, San Jose, Feb. 1997, in press.

[3] Y.S. Derbenv, J. Rossbach, E.L. Saldin, V.D. Shiltsev, “Microbunch Radiative Tail-Head Interaction,” (DESY) TESLA-FEL **95-05**, 1995.

[4] T. Raubenheimer, “Summary of Linac Working Group,” *Micro Bunches Workshop, Upton, NY, AIP Conf. Proc.* **367**, pp.94-106, 1995.

[5] L. Burkel et al., “The Insertion Device Magnetic Measurement Facility: Prototype and Operational Procedures,” *Argonne Tech. Bulletin*, **ANL/APS/TB-12**, 1993.

[6] R. Dejus and A. Luccio, “Program UR: General Purpose Code for Synchrotron Radiation Calculations,” NIM **A347**, pp. 61-66, 1994.

[7] N. Vinokurov et al., “Design Considerations for the Magnetic System of a Prototype X-ray FEL,” *SPIE Lase ‘97 - Free-Electron Laser Challenges Conf.*, San Jose, Feb. 1997, in press.