The APS SASE FEL: STATUS AND COMMISSIONING RESULTS*

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Abstract

A self-amplified spontaneous emission (SASE) free-electron laser (FEL) is under construction at the Advanced Photon Source (APS). Three gun systems, an rf-test area, laser room, numerous diagnostics, a transfer line at the end of the linac, and a new building, which will serve as the experimental hall, have been added. The only remaining items to be installed are the undulators into the beamline. Here, the additions to the APS in support of this project as well as commissioning results and future plans will be discussed.

1 INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) has constructed an experiment designed to test, at a modest scale, the idea of a linac-driven free-electron laser (FEL) based on the single-pass self-amplified spontaneous emission (SASE) process [1]. The project resembles the current conception of a future fourth-generation synchrotron light source user facility [2]. Such a user facility would provide a light source with unprecedented brilliance and time-resolution capabilities far exceeding those currently available at third-generation light sources (including the APS.)

This paper will describe the APS SASE FEL. In particular, a brief overview of the project and its history will be given along with the project goals. The most recent commissioning results will then be discussed along with a brief summary of the immediate timeline.

2 PROJECT DESCRIPTION

The APS SASE FEL project will perform an end-to-end test of the SASE FEL process similar to that envisioned for a fourth-generation synchrotron light source facility. The initial goal will be to obtain saturation at visible wavelengths. The process will be thoroughly studied before raising the electron beam energy to push the FEL wavelength into UV. This process will be continued until the maximum energy of the APS linac is reached. Table 1 lists the experimental parameters for the three planned phases of the experiment.

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Table 1: APS SASE FEL parameters with photocathode rf gun drive

Parameter	Phase I	Phase II	Phase III
Energy (MeV)	217	457	700
λ_R (nm)	530	120	51
L_{gain} (m)	0.4	0.72	1.2
L_{sat} (m)	8.7	15	24
P_{peak} (MW)	260	270	200
$B_{peak}^{\dagger}$ ($\times 10^{28}$)	5	20	37

†photons/sec/mm^2/mrad^2/0.1% bandwidth

3 COMPONENT DESCRIPTION

3.1 RF Gun Systems

There are three electron gun systems in the APS linac: two thermionic rf guns with alpha-magnet bunch compression and a photocathode rf gun.

Figure 1 shows the current configuration of the linac in the area of the two thermionic rf gun systems, either of which can serve as the primary injector for standard APS operation. Only the second, downstream thermionic rf gun is suitable as an FEL driver. The simulated expected performance of this downstream high-performance thermionic rf gun at the entry of the first accelerating structure is 150-A peak current, 5 π mm-mrad rms normalized emittance, and 10% energy spread (with energy filter installed) at 2.5 MeV.

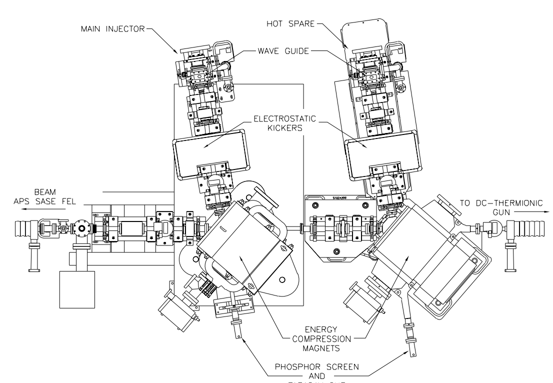

Figure 1: The two thermionic rf guns in the APS linac

In addition to the thermionic rf guns, an on-loan copy of the BNL/ATF-Gun-IV photocathode rf gun was installed at the head of the APS linac during the March 1999 maintenance period (Figure 2.) The photocathode rf gun system can produce a beam at 5 MeV with 300-A peak current, 3 π mm-mrad rms emittance, and 0.1% energy [3]. It will be used as the primary electron source for the APS SASE FEL.

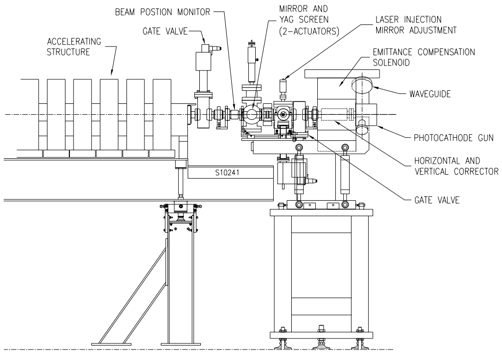

Figure 2: The photocathode rf gun in the APS linac

3.2 Laser System

The photocathode rf gun drive-laser system resides in a radiation shielded room immediately adjacent to the upstream end of the linac vault. The 119-MHz, Nd:Glass laser oscillator produces 260 fs FWHM pulses timing stabilized to better than 1 ps rms. A single pulse at 5 Hz is sent to the Nd:Glass regenerative amplifier. The amplified IR pulse is then up-converted to the UV. The maximum energy of the UV pulse is 400 μJ. Some bandwidth is lost in the amplification process, and so the minimum UV bunch length is ~1.5 ps FHWM.

3.3 Linac

The APS linac is composed of fourteen 3-m, 2856-MHz, SLAC-type, constant-gradient accelerating structures powered by six 35 MW klystrons, three of which are SLEDed. One klystron is used to power both a single accelerating structure and one of the two thermionic rf guns. Here, two high-power rf switches are used to select between either gun or an rf load. The sixth klystron is used is to drive the PC rf gun. The linac is capable of producing electron beam energies of up to 650 MeV.

In addition to the acceleration and requisite transverse focusing quadrupoles, the linac is equipped with many beam diagnostics. These include current monitors; beam-position monitors; Chromox, YAG, and optical transition radiation (OTR) screens; two spectrometer systems; bunch length measurement capability through a higher harmonic rf cavity or by use of a streak camera/OTR screen system; as well as all rf power and phase measurement diagnostics.

3.4 Transfer Lines

Originally, the beam from the linac was sent directly to the positron accumulator ring (PAR). For the FEL experiment, however, the beam follows a different path through a new beamline system. This additional beamline is directly in line with the linac and so avoids unnecessary bends, which could lead to emittance dilution. It is fully instrumented with appropriate diagnostics.

3.5 Undulator System

The undulators chosen for this FEL project are based on the standard undulator used in the APS. Table 2 lists the main undulator parameters.

Table 2: APS SASE FEL undulator parameters

Parameter	Value
Undulator Period [cm]	3.3
K	3.1
Peak On-Axis Field [T]	1.006
Undulator Length [m]	2.4
Cell Length [m]	2.7265
Peak Quadrupole Gradient [T/m]	16
Quadrupole Effective Length [mm]	56

A simple planar undulator system is used. For simplicity, the natural focusing of the undulator in the non-wiggle plane is used. Additional focusing in the orthogonal plane will be performed using quadrupoles placed in gaps between undulator sections. The required undulator system is made up of a series of undulator cells each 2.7265 m in length, of which 2.4 m is undulator. The remaining space is reserved for the combined function quadrupole/corrector magnets, diagnostics, and drift space.

The diagnostics in each undulator cell include a YAG fluorescent screen, wire position monitors, a mirror to pick off the generated light, and a very high resolution beam position monitor capable of single-pass submicron measurements [4].

3.6 Undulator Hall and End Station Building

The hall housing the FEL undulator system is 3.5 m in width and nearly 50 m in length. It is a separate radiation zone, and therefore access is permitted during standard APS operation. It is a concrete enclosure with earth berm used as integral shielding. The building was designed to house two beamlines both fed from the linac. This will allow testing of a beam-switchyard, multiplexed system as envisioned for fourth-generation light source facilities.

Attached to the end of the undulator hall is an end-station building. It is outside the radiation environment and may be occupied when beam is being delivered to the undulator hall. There are staggered penetrations for extraction of the undulator light. Additional optics in a transition area are used to send the light to the optical diagnostics benches in the end-station building. Also, this end-station building houses most of the technical services that power and control the equipment within the undulator hall.

4 COMMISSIONING RESULTS

4.1 Thermionic RF Gun

The high-performance thermionic rf gun is routinely used for APS operation, and so most tuning to date has been toward that goal [5,6]. Commissioning of diagnostics and diagnostic tools is still underway [7].

4.2 Laser System

The laser system is fully operational and all optical transfer lines into the radiation enclosures have been installed and aligned; however, fine-tuning of performance is ongoing. The laser system was used to generate photoelectrons from the photoelectron rf gun while the gun was located in the rf test area.

4.3 Photocathode RF Gun

Very preliminary testing of the PC rf gun was performed while it was located in the rf test area. This testing consisted of full rf conditioning and photoelectron production. It was then relocated to the head of the linac and is waiting dedicated commissioning time [8].

4.4 Beamlines and Diagnostics

Using the thermionic rf gun, the transfer line was commissioned to the beam dump at the end of the undulator hall in February 1999. Figure 3 shows a beam image on the YAG screen at this end dump. Calibration and testing of the diagnostics system are now underway [9]. When beamline commissioning is complete, the first two undulators will be moved in place and first SASE FEL experiments will begin.

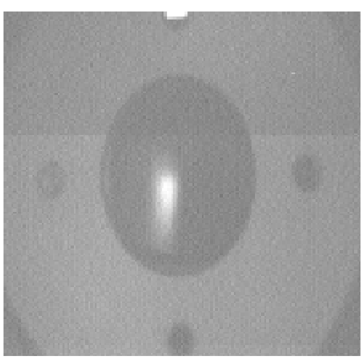

Figure 3: First beam at the end of the beamline.

5 IMMEDIATE TIMELINE

In April of 1999, the first two undulators will be installed. The photocathode rf gun will be ready to send beam to the undulator hall at this time.

A minimum of three undulator cells will be installed in the summer of 1999. Provided beam quality is sufficient, full saturation should be possible in the visible (Table 1). More undulators will be arriving at a rate of about one per month. Following success in the visible, the beam energy will be raised and additional undulators added. Full saturation in the UV will then be attempted. This process will be continued until the full energy of the APS linac is reached.

6 SUMMARY

The APS FEL system represents a prototypical fourth-generation synchrotron light source and will be used to explore the many issues required to build a new synchrotron light source user facility in the future. Many components of the APS FEL are installed and commissioned. The first two undulators will be installed in April 1999 and FEL gain should be observed shortly afterwards. Additional undulators will be installed in the summer of 1999 and full saturation in the visible should be achieved.

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REFERENCES

[1] S.V. Milton, et al., "The FEL Development at the Advanced Photon Source," Proceedings of Free Electron Laser Challenges II, SPIE San Jose, January 1999.

[2] 10th ICFA Beam Dynamics Panel, Workshop on 4th Generation Light Sources, ESRF, Grenoble, January 1996.

[3] M. Babzien, I. Ben-Zvi, P. Catravas, J.-M. Fang, T.C. Marshall, X.J. Wang, J.S. Wurtele, V. Yakimenko, and L.-H. Yu, Phys. Rev. E **57**, 6039, 1998; F. Sakai, X.J. Wang et al., "Development of High Duty Factor Operation RF Photoinjector," BNL-65003, Proceedings of the 11th Symposium on Accelerator Science and Technology, Spring-8, Hyogo, Japan, October 21-23, pp. 473-475 (1997).

[4] E. Gluskin et al., "The Magnetic and Diagnostic Systems for the Advanced Photon Source Self-Amplified Spontaneously Emitting FEL," Proc. of the 18th Int. Free-Electron Laser Conf., Williamsburg, Aug. 1998, to be published.

[5] J. Lewellen, "Operation of the APS RF Gun," 1998 Linear Accelerator Conference, Chicago, Aug. 1998, to be published.

[6] J. Lewellen, "A Hot Spare Injector for the APS Linac," these proceedings.

[7] A. Lumpkin et al., "High Brightness Beam Diagnostics for the APS Linac," these proceedings.

[8] S.G. Biedron et al., "The Operation of the BNL/ATF Gun-IV Photocathode RF Gun at the Advanced Photon Source," these proceedings.

[9] A. Gorski and R. Lill, "Construction and Measurement Techniques for the APS LEUTL Project RF Beam Position Monitors," these proceedings.