

THE OPERATION OF THE BNL/ATF GUN-IV PHOTOCATHODE RF GUN AT THE ADVANCED PHOTON SOURCE*

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Abstract

At the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), a free-electron laser (FEL) based on the self-amplified spontaneous emission (SASE) process is nearing completion. Recently, an rf photoinjector gun system was made available to the APS by Brookhaven National Laboratory/Accelerator Test Facility (BNL/ATF). It will be used to provide the high-brightness, low-emittance, and low-energy spread electron beam required by the SASE FEL theory. A Nd:Glass laser system, capable of producing a maximum of 500 μJ of UV in a 1-10 ps pulse at up to a 10-Hz repetition rate, serves as the photoinjector's drive laser. Here, the design, commissioning, and integration of this gun with the APS will be discussed.

1 INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) is currently commissioning a free-electron laser (FEL) based on the self-amplified spontaneous emission (SASE) process [1]. This project, referred to as the APS SASE FEL, is designed to achieve saturation in the visible, UV, and ultimately VUV wavelengths. To assist in producing the beam required for saturation in the shortest possible distance, the APS has installed an on-loan copy of the Brookhaven National Laboratory/Accelerator Test Facility (BNL/ATF) high-brightness photoinjector, GUN-IV, at the head of its linac. This paper will discuss the gun design, drive-laser, integration with the APS systems, commissioning, and future plans.

2 RF GUN DESIGN

A performance enhanced version of the traditional BNL/ATF 1.6-cell 2856-MHz photocathode rf gun system [2] will be used. These enhancements include symmetrization of the rf fields [3] and an upgrade to

insure performance at high repetition rates [4]. The solenoidal field is used to control transverse emittance dilution [5].

3 THE APS DRIVE LASER

The drive-laser system consists of a mode-locked, diode-pumped Nd:Glass oscillator coupled to a Nd:Glass regenerative amplifier. The 119-MHz oscillator can produce 260 fs FWHM bandwidth-limited pulses centered at 1053 nm. The repetition rate of the oscillator is the 24th subharmonic of the accelerating field. The oscillator average output power is approximately 100 mW and is timing stabilized to < 1 ps rms. The regenerative amplifier is capable of producing 5 mJ in the IR and, after frequency quadrupling, ~ 500 μJ in the UV. During the amplification, some bandwidth is lost; therefore, the shortest pulse produced by the amplifier is roughly 1.5 ps FWHM. This is sufficiently short, based on the requirements of the photoinjector, and can be easily lengthened if so desired. The amplifier is capable of operating at up to 5 Hz, with a best effort repetition rate of 10 Hz.

4 PHOTOINJECTOR SYSTEM

Figure 1 shows the layout of the photoinjector at the APS. A copper cathode is used, since the energy output of the drive laser is capable of producing sufficient quantum efficiency with this metal. In addition, copper will reduce the amount of time dedicated to laser cleaning and cathode replacement, and, since it is robust compared to other commonly used cathode materials, such as yttrium (Y) and magnesium (Mg), will also reduce the risk of cathode damage. The gun is driven by the UV laser beam at near normal incidence from an input mirror just after the solenoid magnet as opposed to the more difficult 70° incidence through two available laser ports. This input mirror is mounted on a rotatable *in vacuo*, micrometer, which provides the vertical positioning of the mirror as well as the horizontal positioning of the laser.

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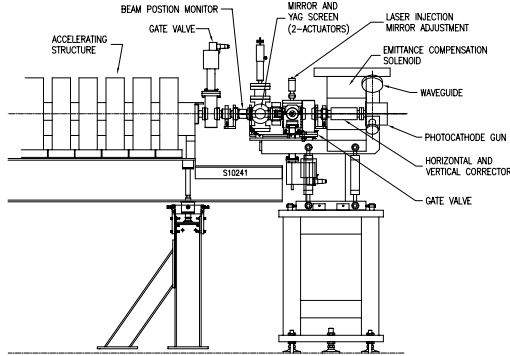


Figure 1: The photoinjector as installed in the APS linac

There is a vacuum pump on the gun itself, the waveguide, and immediately following the solenoid magnet. There are two gate valves: one just after the solenoid exit and one immediately following the beam position monitor. This allows for easy maintenance of the beamline components between the gun and the rest of the linac when needed.

Since the drive laser is not entering the gun via either of the 70° laser ports, the ports are instead used for a cathode inspection light and cathode imaging in the visible and UV. There are three corrector magnets: one inside the bore of the solenoid assembly, one immediately after the exit of the solenoid, and one just after the laser injection port. Just before this injection port is an integrating current transformer, and just downstream lies a two-way actuator assembly. One arm contains a YAG screen and the other maintains a mirror for additional cathode inspection. After the actuator assembly is a stripline BPM. Additional diagnostics include thermocouples for monitoring the gun and waveguide temperatures, rf power readbacks, and a heliix cable from the gun's rf pick-up loop for on-line cavity tuning.

6 RECENT RESULTS, PROGRESS, AND FUTURE PLANS

The BNL/ATF 1.6-cell 2856-MHz photocathode rf gun was fully conditioned with rf power in four days in December 1998 in a recently constructed rf test area. First photoelectrons were achieved with $\sim 25 \mu\text{J}$ in the UV (263 nm) on March 8, 1999, with 8 MW forward power at the gun. This translates into nearly 102 MV/m and 5.0 MeV electrons. Figure 2 shows the first captured image on the YAG screen of such photoelectrons. Many of the diagnostics listed above, other than the YAG screen, were not available in this rf test area, since they were being prepared for the photoinjector installation into the linac. The charge, therefore, was unfortunately not available in conjunction with these first electrons to compare with the total input photon energy. It was, however, estimated as $\sim 50 \text{ pC}$, derived from the work



Figure 2: First photoelectrons; March 8, 1999

function of copper and a previously proven quantum efficiency of $\sim 1 \times 10^{-5}$, based on the preparation of this copper cathode [6]. The dark current was barely observable on the YAG screen. The purpose of this run in the rf test area was to prove the operational readiness of the photocathode rf gun before installation into the linac.

The photoinjector system was installed at the head of the APS linac on March 12, 1999, replacing the original source, a thermionic DC gun, pre-buncher, and buncher. Here, the photocathode rf gun has a water flowrate of 6.1 liters/minute (1.6 gallons/minute) at a temperature of $50 \pm 0.1^\circ\text{C}$. The four water channels, which provide water to the cathode, half cell, full cell, and gun waveguide, respectively, have separate flow regulation to assist in maintaining the desired temperature stability. Additional thermal insulation has been installed around the gun. The solenoid is cooled to a temperature of $32 \pm 1^\circ\text{C}$. With respect to the waveguide system, there is a water-cooled rf window isolating the gun from the rest of the rf delivery system. Just after this window is a 3-dB hybrid that helps to reduce excess reflected power to the klystron. The modulator and klystron assembly are capable of providing 35-MW forward power with repetition rates up to 30 Hz and rf pulses ranging from 0.1-10 μs , which is well above the $\sim 8 \text{ MW}$ at 5-10 Hz in 1-3 μs required for optimal operation.

Before the waveguide between the gun's isolation window and the rest of the run were connected, a launcher was attached onto the isolation window. Two microwave measurements were then taken to insure the tune in the gun's cavities was correct after being moved and reinstalled. A 10-W amplifier was used to drive the gun through the launcher. The network analyzer measurements of the reflection (S_{11}) and transmission (S_{21}) were obtained and are shown in Figures 3 and 4, respectively. From these and previous measurements, we found a loaded Q of 5700 and, assuming a coupling beta close to one, yields an unloaded Q of ~ 11400 . The 0- and π - mode separation is 3.40 MHz.

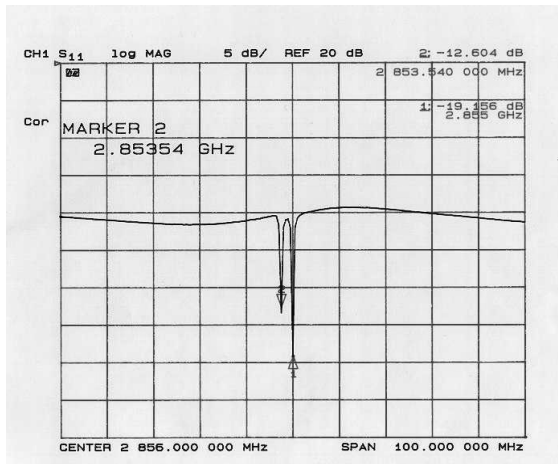


Figure 3: Reflection measurement

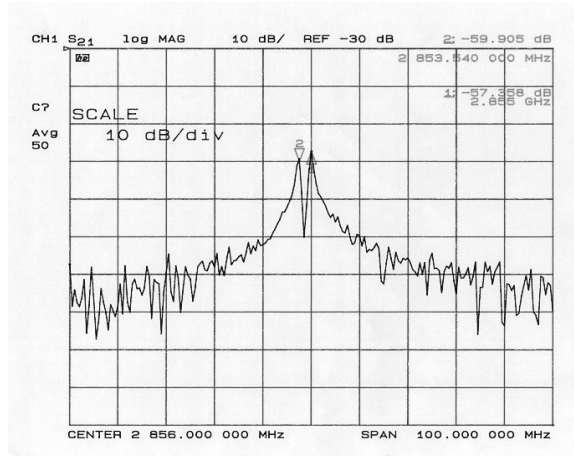


Figure 4: Transmission measurement

Previous to the photocathode gun installation at the head of the linac, two thermionic rf guns with corresponding alpha magnets were fully integrated into the linac. Their location is just downstream of the first SLAC-type, 3-m accelerating structure. They now serve as the primary injectors for the APS [7]. The second thermionic rf gun, nearest to the second downstream accelerating structure, was used to commission the APS SASE FEL beamline in February 1999. Although this thermionic rf gun will continue to be used in further APS SASE FEL commissioning, the BNL/ATF photoinjector will serve as the main injector for this project, since it is capable of producing the high-brightness, low-emittance, low-energy spread, and high peak current electron beam required to best satisfy the SASE theory [8]. The parameters of these two guns to be used with the APS SASE FEL may be found in Table 1.

Table 1: Expected photocathode rf and measured thermionic rf gun parameters

Parameter	Photocathode	Thermionic
Energy [gun exit]	5 MeV	5 MeV
Repetition rate	1-5 Hz	1-10 Hz
Emittance	3π mmmrad	10π mmmrad
Peak current	300 A	150 A
Energy spread	0.1%	0.5%

Preliminary alignment of the drive laser to the cathode center was performed during the March 1999 general maintenance period. The photocathode rf gun system verification and check-out is underway, and full commissioning of the linac and APS SASE FEL beamline with this new injector is expected to begin in April 1999.

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7 REFERENCES

- [1] S.V. Milton et al., "FEL Development at the Advanced Photon Source," Proceedings of Free Electron Laser Challenges II, SPIE, January 1999, to be published; S.V. Milton et al., "The APS SASE FEL: Initial Commissioning Results," these proceedings.
- [2] X.J. Wang et al., "Design and Construction of a Full Copper Photocathode Gun," Proc. 1993 Part. Accel. Conf. (1993) p. 3000.
- [3] D.T. Palmer, X.J. Wang, et al., "Beam Dynamics Enhancement due to Accelerating Field Symmetrization in the BNL/SLAC/UCLA 1.6 Cell S-Band Photocathode RF Gun," Proc. 1997 Part. Accel. Conf. (1997) p. 2846.
- [4] 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).
- [5] B.E. Carlsten, NIM in Phys. Res. A285 (1989) 313-319.
- [6] T. Srinivasan-Rao, J. Yu, and X.J. Wang, "Study on the Sensitivity of Quantum Efficiency of Copper Photocathodes on Sample Preparation," BNL-62626 (1996).
- [7] J.W. Lewellen, S. Biedron, A. Lumpkin, S.V. Milton, A. Nassiri, S. Pasky, G. Travish, M. White, "Operation of the APS RF Gun," Proceedings of the XX International Linear Accelerator Conference, Chicago, Illinois, August 23-28, 1998, to be published; J.W. Lewellen, K. Thompson, J. Jagger, S.V. Milton, A. Nassiri, M. Borland, D. Mangra, "A Hot-Spare Injector for the APS Linac," these proceedings.
- [8] 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