OPERATION OF THE APS RF GUN*

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Abstract

The Advanced Photon Source (APS) has a thermionic-cathode rf gun system capable of providing beam to the APS linac. The gun system consists of a 1.6-cell thermionic-cathode rf gun, a fast kicker for beam current control, and an alpha magnet for bunch compression and injection into the APS linac line. This system is intended for use both as an injector for positron creation, and as a first beam source for the Low-Energy Undulator Test Line (LEUTL) project [1]. The first measured performance characteristics of the gun are presented.

1 INTRODUCTION

The APS injection system currently uses a 100-kV DC thermionic-cathode gun as its main electron beam source, followed by five 3-meter sections of S-band linac structures, as a means for providing beam to a positron conversion target. The principal measures of electron beam quality have been beam current at the positron target and positron generation efficiency. The transverse beam quality provided by the DC gun, however, is insufficient for many planned experiments utilizing the APS linac system.

The APS linac now includes a thermionic-cathode rf gun system. An alpha magnet bunch compressor is used to inject beam into the linac line between the first and second 3-meter linac sections. Although the rf gun system cannot provide as much current as the original DC gun system, the beam brightness is higher, and it is suitable as a source for some of the experiments slated to use the APS linac line. Because of the gun's placement in the APS electron linac line, beam energy at the positron target is limited to approximately 175 MeV instead of the nominal 220 MeV the full line can provide.

We have begun to characterize the performance of the thermionic-cathode gun in light of its potential as a hot spare for the DC gun. The performance measurements completed to date are presented, along with additional measurements relating to the suitability of this gun for other experiments using the APS linac line.

2 OVERVIEW OF THE RF GUN SYSTEM

The rf gun system includes the gun itself, the transport line from the gun to the entrance of the linac section, a fast crossed-field kicker used to limit injected charge, and various diagnostics. A schematic of the system is shown in Figure 1.

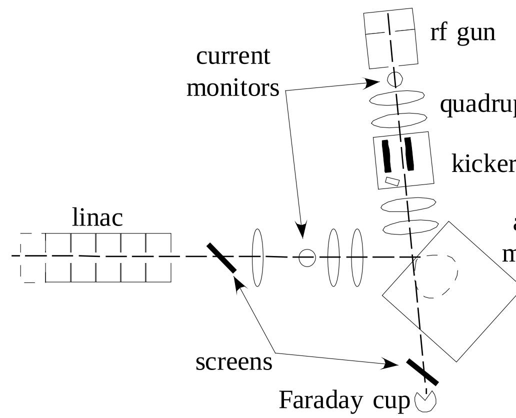

Figure 1. Schematic layout of the rf gun beam transport optics and diagnostics. Steering correctors are not shown.

2.1 *Rf Gun Properties*

The rf gun itself is a 1.6-cell π-mode structure. Up to 7 MW of rf power can be supplied to the full cell via an end-coupled waveguide, with a side-coupled cavity providing power transfer from the full cell to the cathode cell. The cathode used is a tungsten dispenser cathode with a diameter of 6 mm. The gun can produce peak beam energies of up to 4.5 MeV (kinetic) and peak macropulse currents of up to 1.3 A. Expected beam emittances and peak currents vary considerably with beam energy and current, but are expected to be as low as 5 π mm mrad (normalized rms) and as high as 150 A, respectively. More details of calculated gun performance may be found in [2].

2.2 *Diagnostics*

Several diagnostics are located along the rf gun beamline. A current transformer is located immediately after the exit of the gun and provides measures of beam current and total charge emitted. A combination Faraday cup and viewscreen is located on the far side of the alpha magnet from the gun, so kicker system tuning can be performed with the alpha magnet off.

Other diagnostics, such as fluorescent and transition radiation screens, beam position monitors (BPMs), spectrometers, and bunch length monitor cavities, are

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present at various locations along the linac line for further characterization of the rf gun beam properties.

2.3 Gun-to-Linac Transport Line

The beam from the rf gun is injected into the second 3-meter linac structure via an alpha magnet. This alpha magnet also serves as a bunch compressor. An asymmetric transport lattice of four quadrupoles before the alpha magnet and three following the alpha magnet is used. The calculated beam size for a typical set of gun parameters is shown in Figure 2, from the exit of the rf gun to the entrance of the linac. The simulation code **elegant** [3] was used for all transport simulations external to the rf gun.

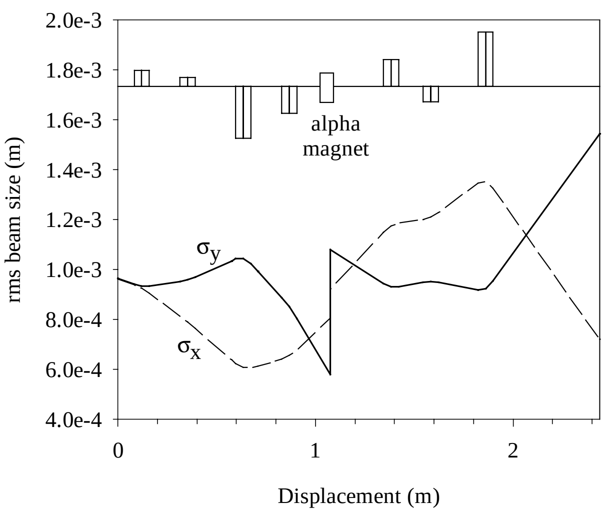

Figure 2. calculated beam spot size for a typical set of rf gun operating conditions. The discontinuity of the beam size at the alpha magnet is due to the use of transport matrix modeling formalism through the magnet.

2.4 Kicker System

The rf gun system includes an electric/magnetic crossed-field kicker system to limit the total current injected into the linac line. [4] A permanent magnet is used to deflect the beam from the gun into a beam dump; when the kicker fires, a delay line is used to provide a bucking E-field for 40 ns.

Proper kicker operation was verified by operating the rf gun and kicker with the alpha magnet off, and observing the current transmitted to the combination fluorescent screen and Faraday cup located straight-through the alpha magnet. A plot of the full current macropulse from the rf gun, and transmitted beam current detected on the Faraday cup, is shown in Figure 3. The noise on the current monitor signal trace is due to the kicker firing. Simulations indicate that a maximum of 75% of the total beam current can be transmitted to the Faraday cup if the beamline is optimized for such transport. For Figure 3, the beamline was optimized for injection into the linac so the transmitted current is slightly lower.

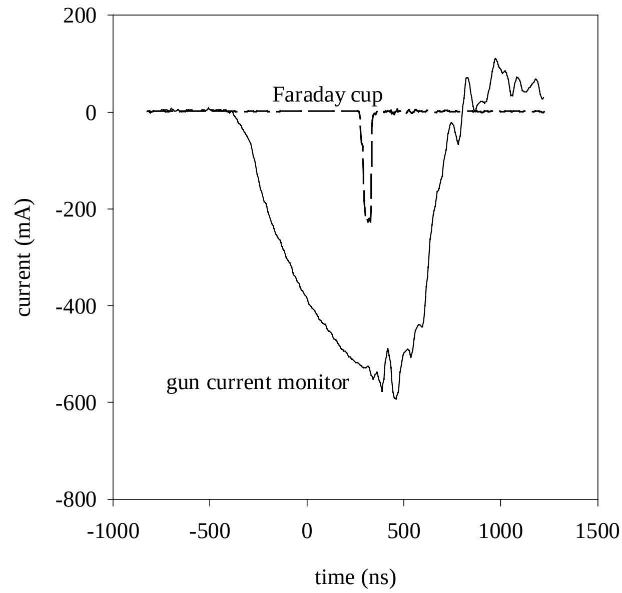

Figure 3. Gun current monitor and Faraday cup signals.

3 SYSTEM PERFORMANCE

3.1 Transport Efficiency and Energy Gain to the Positron Target

Electron beam transport efficiency measurements were made using the current monitors located in the rf gun beamline and the BPM sum signals from the APS linac diagnostics. Approximately 70% of the total charge emitted from the gun can be injected into the linac. The majority of the loss occurs over the length of the gun-to-linac transport line in the low-energy tail of the beam, which would be lost in any event during linac capture. Losses along the linac line are measured using the linac BPM sum signals. From after injection into the linac, about 85% of the beam can be transported to the positron target at high rf gun currents (~600 mA), and essentially all of the beam can be transported to the positron target at low rf gun currents (~200 mA).

An energy spectrometer immediately upstream of the positron target was used to measure the electron beam energy and energy spread at the end of the electron linac. The peak beam energy was found to be approximately 175 MeV. The beam energy was measured as a function of the phase between the linac sections and the rf gun, for a constant alpha magnet current (see Figure 4). The minimum rms energy spread found was 0.5% and was achieved by varying the linac-to-gun rf phasing and minimizing the spot size on the spectrometer screen.

Positron conversion efficiency was also measured at rf gun beam currents of 200 mA and 600 mA. In both cases, measured conversion efficiency was on the order of 0.3% - 0.5%, depending more upon final focusing and positron linac setup than beam current. These efficiencies are in the expected range, given the target design and beam energy.

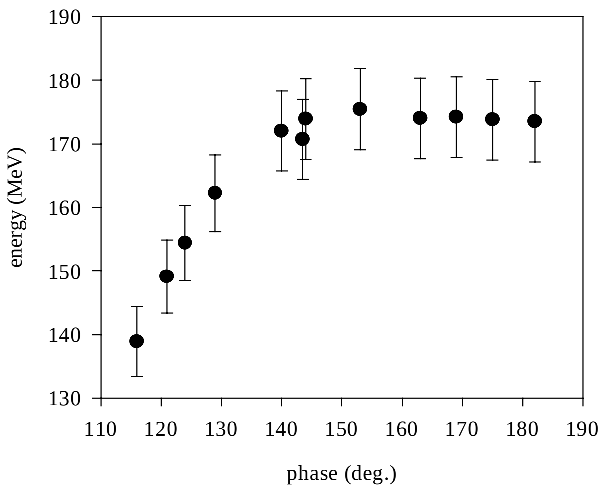

Figure 4. Peak electron beam energy vs. phase between the rf gun and linac. The error bars represent uncertainty in centroid location and spectrometer calibration.

3.2 Bunch Length Measurements

The APS linac includes a fifth-harmonic (of the linac frequency) rf cavity intended for real-time bunch length diagnostic measurements. The cavity is located upstream of the positron target and downstream of the energy spectrometer magnet [5].

No direct calibration of the cavity signal to actual bunch length has been made using the rf gun. We can vary the cavity output signal considerably simply by varying the linac-to-gun phase relationship while maintaining constant delivered current. Thus, the cavity appears to be functional and, once the cavity signal can be calibrated to beam current and correlated with streak-camera measurements, should provide real-time bunch length measurements.

Using a fast diode and scope, we can observe the buildup of rf power in the fifth-harmonic cavity. The signal builds up over a period of approximately 40 ns, then begins to decay. This is consistent with the duration of the electron beam passed by the kicker system.

A plot of observed signal strength vs. alpha magnet current is shown in Figure 5. For this measurement, the beam current from the gun was stabilized at 200 mA, with an input rf power of 3.5 MW. The relative rf phase between the gun and linac was varied to obtain the minimum energy spread on the spectrometer magnet, which should correspond to the minimum bunch length. In Figure 5, the fifth-harmonic cavity signal strengths have been normalized to the square of the beam current at the positron target.

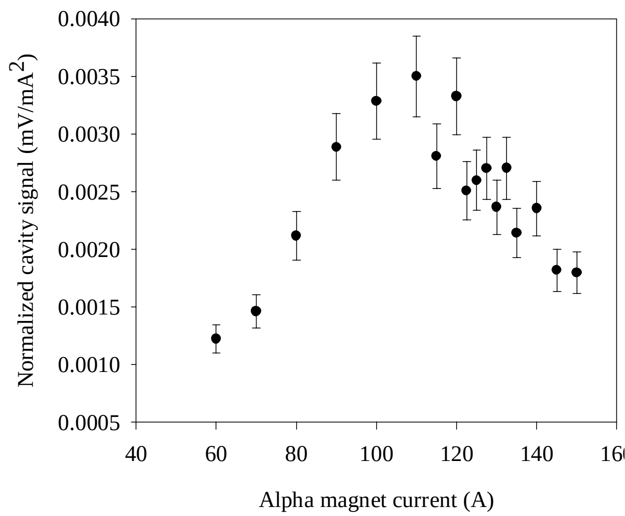

Figure 5. Fifth-harmonic cavity signal as a function of alpha magnet current, normalized to electron beam current. The signal strength is inversely proportional to the bunch length divided by the beam current squared.

We have also measured bunch lengths on the order of 3 – 6 ps using a streak camera and are in the process of calibrating the fifth-harmonic cavity with the streak camera measurements.

4 CONCLUSIONS

The commissioning process for the thermionic-cathode rf gun is proceeding well. Reasonable beam transport along the APS linac line has been achieved. Positron conversion efficiency has been measured and indicates that the rf gun could be used to fill the APS storage ring if required, albeit at a reduced rate. Bunch length measurements are in progress, and a fifth-harmonic cavity is being correlated to streak camera measurements for use as a real-time bunch length monitor. Beam emittance measurements are also planned.

5 REFERENCES

[1] S.V. Milton et al., “Status of the Advanced Photon Source low-energy undulator test line,” *NIM A* **407** (1998) 210-214.

[2] M. Borland, private communication

[3] M. Borland, “User’s Manual for **elegant**,” APS online document, Program Version 12.4, December 1993

[4] Y. Kang et al., “Beam Chopper for the Low-Energy Undulator Test Line (LEUTL) in the APS,” *Proc. 1997 Part. Acc. Conf.,* Vancouver, BC (to be published)

[5] A. Nassiri and A. Grelick, “A Fifth Harmonic RF Bunch Monitor for the ANL-APS Electron Linac,” *Proc. 1993 Part. Acc. Conf.,* Washington, DC, 2412 (1993)