A FLEXIBLE INJECTOR TEST STAND DESIGN*

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Abstract

The Advanced Photon Source (APS) has constructed an injector test stand (ITS) for high-brightness electron beam research. The test stand includes three rf ports with independent phase and power control, beamline supports designed for rapid reconfiguration, and a control and diagnostics system based on the design of the APS linac. The beamline design features a high-resolution electron spectrometer that includes provision for operation as a dispersion-free dogleg, and a rapidly reconfigurable gun-to-spectrometer transport line. Picosecond and nanosecond photocathode drive lasers are available; the room shielding is also adequate for the high average beam powers typically produced by thermionic-cathode rf guns.

The initially installed gun is a ballistic-compression gun, which requires all three rf ports to be connected to the gun. Plans include the installation of a higher-order mode photoinjector, requiring one rf connection; this will free the other ports to provide power to a small TW linac section and deflector cavity for bunch-length measurements. The test stand is also capable of being used as an operator training facility, and serves as a validation facility and test bed for the APS main injector rf guns.

INTRODUCTION

Rf electron guns, in various forms, are key elements of many current and projected accelerators. Typically, rf guns are split into two distinct categories: those using thermionic cathodes to generate electrons and those using photocathodes. The choice of cathode and other design features such as the number of cavities in the gun, cavity coupling schemes, and cavity interior geometry, is heavily influenced by the task the gun is designed to address.

Photocathode rf guns use an external drive laser to cause electrons to be emitted from the photocathode. This type of gun is generally selected for tasks requiring high-brightness beams, single-bunch or widely-spaced bunch operation, and relatively high charge per bunch. Although there are exceptions, these guns are typically used for experimental purposes, as distinguished from “operational” systems; this is often due to the maintenance issues frequently associated with the drive laser and photocathode.

Thermionic-cathode rf guns use a heater to generate thermal electron emission from the cathode surface. This type of gun produces beam as long as rf is applied to the cavity, and can generate very high average beam currents. This is usually the gun type of choice when high-charge, single-bunch operation is not important, and when beams of only moderate transverse brightness are required. Due to their high reliability and simplicity of operation, they are often chosen for “operational” roles such as beam sources for electron storage rings; this type of gun has also been used for long-wavelength free-electron laser experiments.

The APS presently has installed two thermionic-cathode guns to serve as sources for filling the storage ring and one photocathode gun to serve as the beam source for a single-pass FEL experiment and nascent user program. Thus, we have a need for an injector test and repair facility that can accommodate both types of injectors in use at the APS. In addition, the APS injector test stand is intended to facilitate the testing of new injector designs, to provide for an operational test bed for new diagnostics or hardware intended for installation in the APS injector complex, and to act as a training facility for accelerator operators when the storage ring is running in top-up mode.

PRESENT CONFIGURATION

The APS ITS is effectively an independent accelerator enclosure from the rest of the APS, in terms of personnel access and beam permit. Rf power can be delivered to the room as long as the APS linac rf system is enabled.

A ballistic bunch compression (BBC) rf gun is presently installed in the ITS. This gun generated first beam, using a thermionic cathode, on 11 March 2003. The rf power feed system provides independently phased high-power rf to the three independent ports on the BBC gun and is more fully described in [1]. The waveguide network was specifically designed for the BBC gun, but can also be used to power up to three independent rf elements, e.g., a gun, small linac section, and transverse deflection cavity.

The beamline, shown in Figure 1, includes a branch line that can be operated as either a dispersion-controlled dogleg or a spectrometer with a dispersion of 0.5 m. The beamline downstream of the second dogleg dipole is intended for use as a low-energy experimental area. Diagnostics include current monitor toroids, Faraday cup / viewscreen monitors, a dipole field Hall probe, and energy slits in the dispersive beamline. These are commissioning diagnostics and are appropriate for an exploration of the BBC gun operation in energy-compression mode [2]. Other diagnostics, for example an emittance-measurement pepperpot screen or a Golay cell-based bunch length monitor, will be installed as required by the experimental program.

The picosecond drive laser for the APS photoinjector is located adjacent to the ITS enclosure. The optical trans-

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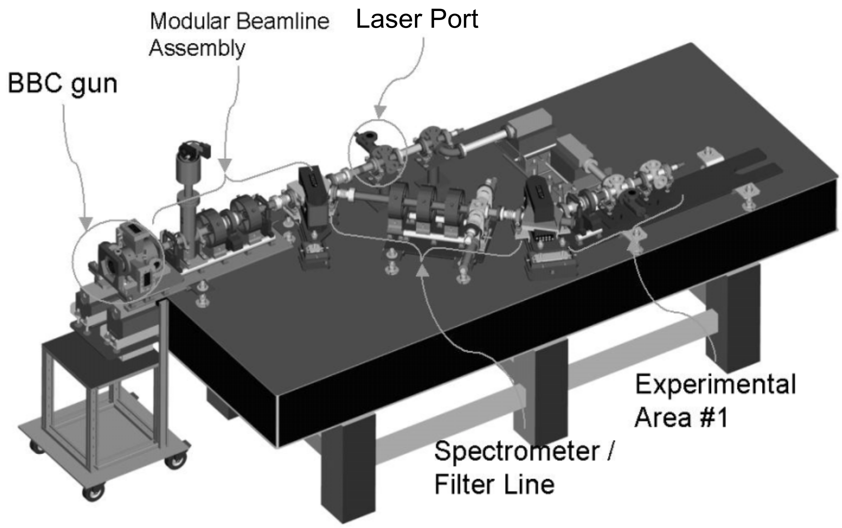

Figure 1: Present layout of the APS injector test stand; the waveguide network is omitted for clarity.

port path to the ITS was removed to facilitate the waveguide installation, but will be restored shortly. In addition, a nanosecond drive laser has been purchased and will shortly be installed in the ITS. An optical switchyard will allow either laser to be used with an installed gun.

All of the quadrupole and corrector power supplies are on quick-disconnect assemblies. This allows the beamline to be rapidly reconfigured or a malfunctioning magnet or power supply to be replaced. The rail support system is modular also; more details can be found in [3]. The entire beamline is built on a standard 1m $\times$ 3m optical table, allowing the rapid addition of either beamline or diagnostic elements.

Finally, the ITS control system uses the same architecture as the rest of the APS. This not only allows the ready use of the entire APS data acquisition and control toolkit, but also allows the room to be used for prototyping new hardware and software before general deployment throughout the APS.

A more thorough discussion of the development history of the ITS and the methods and techniques used in its construction may be found in [4].

INITIAL OPERATION

The BBC gun generated its first beam on 11 March 2003, following conditioning of the waveguide network into high-power loads. The initial operation revealed some interesting and unexpected behaviors of the gun, not surprising in a brand-new gun; subsequent efforts have been focused on improving the performance of the gun and waveguide network.

FUTURE PLANS

Short- and Mid-Term

In the immediate future, the experimental program will focus on four topics: ballistic bunch compression, energy compression, operation of the long-pulse drive laser as an injector gate, and DC/rf photoinjector studies [5].

In the ballistic bunch compression process, the longitudinal phase space of a moderate-energy electron beam is prepared such that the beam will self-compress in the field-free drift region between the exit of the beam source and the entrance of a linear accelerator [6]. As the compression is accomplished without magnetic elements, the beam is not subject to effects such as coherent synchrotron radiation [7]. The APS BBC gun will permit the exploration of the ballistic compression process with both thermionic and photocathodes.

Thermionic-cathode rf guns can serve as the sole accelerators for such devices as compact, far-infrared free-electron lasers [8]. The large energy spread produced by typical guns of this type, however, requires the use of an energy filter and results in much of the beam charge being discarded. By suitable manipulation of the longitudinal phase space, however, the energy spread can be dramatically reduced [2]. This has the effects of simplifying the beamline design as well as improving overall efficiency. The APS BBC gun is suitable for exploring this concept also.

One future requirement for the APS injector complex is the ability of the linac to generate shorter bunch trains at higher total charge levels, in support of enhanced top-up operation, and to reduce the requirement for a low-energy damping / accumulator ring. The use of a nanosecond Q-switched drive laser offers a promising method of gating the beam from a thermionic-cathode rf gun. The APS BBC gun, operating in a π-mode, can mimic the operation of the main injector rf guns. This will allow a thorough exploration and characterization of this technique before installation in the linac tunnel. This is not a physics experiment per se, rather, it is leveraging the use of the ITS as a benefit to APS operations in general.

Future Topics and Possibilities

Longer-term plans include the addition of a 1.6-m, SLAC-type, traveling-wave constant-gradient linac section; fabrication and testing of a higher-order-mode photoinjector; photocathode research; and emittance evolution studies. Also, the ITS will serve as a development platform for long-wavelength radiation production, characterization, and use as a measurement tool. Depending on the desired mode of operation, this may use an energy-compressed beam to drive a compact free-electron laser or a time-compressed beam to generate a broadband pulse via a wiggler or dipole.

The ITS will also start to function as an operator training facility on a more regular basis, as well as providing a means of testing new components with beam. These tasks, while not specifically experimental in nature, will provide a needed service to the operation of the APS and will help to involve more of the APS Operations staff in injector research and development.

Finally, proposed changes in the APS storage ring injector complex will require a significant redesign of the linac electron gun region. The ITS will allow the prototyping and characterization of proposed changes in a timely fashion, with no risk to the operation of the APS linac.

CONCLUSIONS AND SUMMARY

The Advanced Photon Source injector test stand is currently undergoing commissioning. The initial series of experiments will capitalize on the ITS to study topics relating to APS performance enhancement as well as fundamental injector physics. Future upgrades, including the addition of a capture linac section, will significantly increase the range of capabilities of the ITS. Finally, the ITS will also provide service as a training facility for APS accelerator operators and as a means for increasing the involvement of Operations staff in ongoing accelerator physics research projects.

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[7] A good starting point for obtaining information on coherent synchrotron radiation is the Web site for the 2002 CSR Workshop held at DESY-Zeuthen, http://www.desy.de/csr/.

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