LLNL X-BAND TEST STATION STATUS*

R.A. Marsh†, F. Albert, G. Anderson, S.G. Anderson, E.T. Dayton,
S.E. Fisher, D.J. Gibson, S.S. Wu, F.V. Hartemann, C.P.J. Barty
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Abstract

An X-band test station is being built at LLNL to support inverse Compton-scattering x-ray and gamma-ray source development. The major components for the X-band test station have been designed, fabricated, installed, and aligned. The XL-4 klystron has been delivered, dressed and installed in the ScandiNova modulator, and tested to full peak power. Final assembly and bakeout of RF transport, test station supports, and accelerator components is complete, and the current status of commissioning and first beam will be presented and discussed. Future upgrade paths and configuration for a variety of x-ray and gamma-ray applications will be discussed along with schedule for planned experiments.

INTRODUCTION

Extremely bright narrow bandwidth gamma-ray sources are expanding the application of accelerator technology and light sources in new directions. LLNL has a successful history utilizing gamma-rays generated by a linac-driven, laser-based Compton scattering gamma-ray source [1, 2, 3, 4]. Next generation advancements in linac-based x-ray and gamma-ray production require increasing the average flux of gamma-rays at a specific energy (that is, $N/eV/sec$ at the energy of interest). One way to accomplish this is to increase the effective repetition rate by operating the RF photoinjector in a multi-bunch mode, accelerating multiple electron bunches per RF pulse. This multi-bunch mode will have stringent requirements for the electron bunch properties including low emittance and energy spread, but across multiple bunches. An X-band test station is under construction at LLNL to develop multi-bunch electron beams and generate x-rays. This paper summarizes progress and describes the current status of the project.

The RF gun is described in detail in [5]. Test station parameters are summarized in Table 1. Beam dynamics are summarized in Fig. 1 for a 250 pC bunch generated in the Mark 1 X-band RF gun and accelerated by a single T53 traveling wave accelerating section. Beam steering will use X-Y windowpane dipole magnets, and two quadrupole triplets will focus the beam for transport and quad-scan emittance measurement. A dump dipole magnet will double as a spectrometer once it has been calibrated.

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† marsh19@llnl.gov

Table 1: Test Station Parameters

Charge	25–250 pC
Normalized Emittance	<1 mm mrad
Gun Energy	7 MeV
Cathode Field	200 MV/m
Coupling β	1.7
Section Gradient	∼70 MV/m
Final Energy	30 MeV

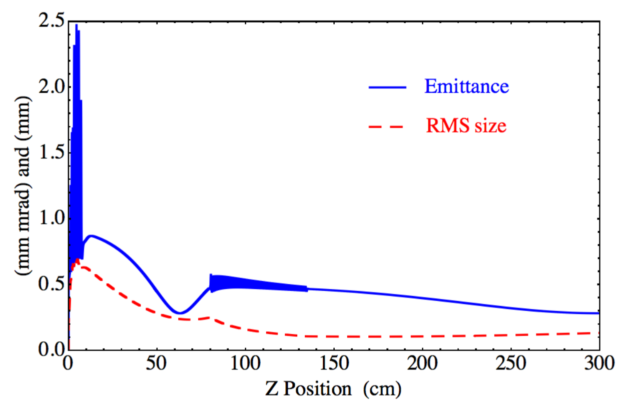

Figure 1: PARMELA beam dynamics simulation for a bunch charge of 250 pC.

TEST STATION

The test station layout is shown in Fig. 2. The high voltage modulator and X-band tube reside in a separate area with RF distribution fed through a hole in the wall to the linear accelerator. A manifold divides the power between the RF gun and the accelerating sections [6]. Testing of the klystron to full power is complete [7], and the RF load tree that was used for this testing is currently being disassembled to provide components for dressing the accelerating sections and provide components for the power division manifold. Support structures made from 80/20 mount to the laser tables and provide multi-dimensional adjustment for alignment of supported components to the beamline. The emittance compensation solenoid for the RF gun is mounted on precision ground rails so that it can be moved back to provide access to the gun. The gun support structure holds the RF gun, WR-90 pumpouts and pumps, as well as an RF gate valve on the beamline. The T53 accelerating structure is mounted on a SLAC designed strongback with end-to-end adjustment, which is then mounted on 80/20 supports that provide additional adjustment as well as support for RF distribution, loads, and vacuum pumps.

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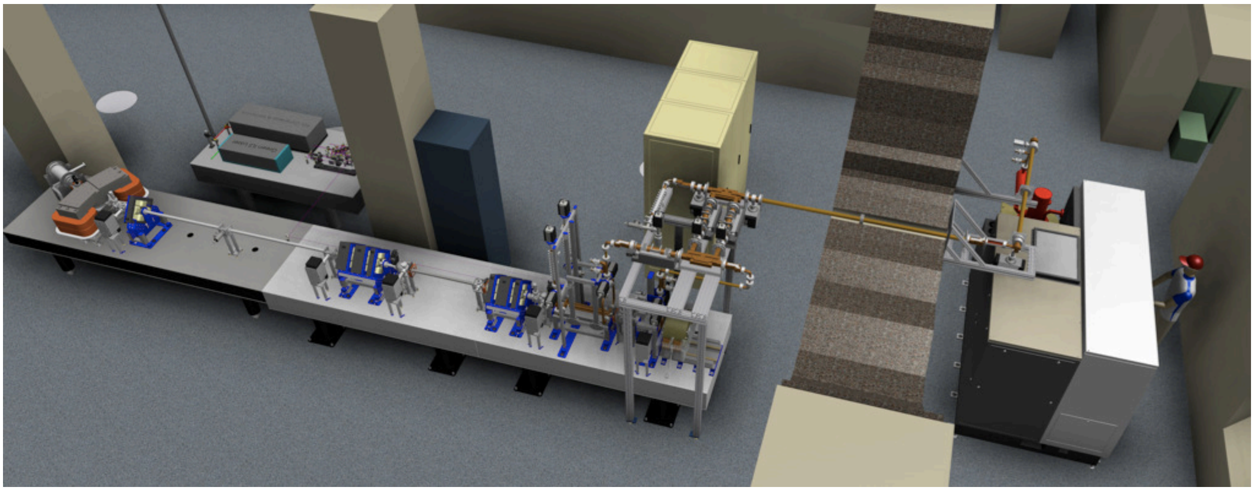

Figure 2: CAD rendering of the X-band test station. Test station position has been changed to optimize the RF distribution for minimal loss and permit for the expansion of the beamline for future experiments.

The quadrupole magnets are mounted together in triplets, with each stand having adjustability. The magnet alignment within their supports has been measured as reported in [8]. The steering magnets are mounted onto beamline vacuum flanges.

Alignment

The alignment specification on most components, driven by the desire to limit emittance growth, is ± 100 μm. As shown in [9], tolerances can become even tighter if emittance growth in low charge bunches is to be limited. An initial alignment procedure was developed for a 250 MeV X-band linac at LLNL [10], which has been adapted to the X-band test station. The general approach for alignment uses a precision CMM arm from Romer, with a quoted specification of ± 75 μm repeatability and volumetric accuracy over the full envelope reachable by the arm. The Romer arm and operating technician can be seen in Fig. 3. Physical contact with a probe tip allows encoders in the arm to map the exact position of each point input into the CMM software. The coordinate system of the arm is based on geometric features of individual components such as the cross-section of magnet pole pieces, or the outer radii of pillbox cell cups, combined with tooling ball fiducials that have been placed on magnets and accelerating structures. Initial measurement of the geometric features allows the external fiducials to be used in the future when features may be less accessible.

The emittance compensation solenoid is the heaviest component, and has the least adjustment (its height from the table is fixed). Magnet metrology measurements at SLAC confirmed that the magnetic and physical axes of the solenoid were aligned to within 25 μm. The solenoid was adjusted so that is was parallel with the laser table, and pointing along the table edge. Solenoid alignment set the coordinate system for subsequent components, with the beamline axis zero set by the mid plane of the Helmholtz

Figure 3: Photograph of X-band test station alignment. Romer CMM arm in use to precisely measure the 3D position of the T53 cells for proper alignment of the accelerating structure with respect to the beamline axis and cathode position.

pair outer pole faces: this will be the center for the RF gun so that there is no field on the cathode surface. Subsequent components are all aligned onto the beamline centerline, at an offset from the cathode driven by beam dynamics and mechanical design.

The RF gun body was aligned on axis with the cathode cell backplane offset so that the internal cathode surface resides at the mid-plane of the solenoid. The RF gun beam-

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line gate valve was also used for alignment of the RF gun support structure given that it is the furthest component downstream of the gun. The T53 section was measured with respect to pillbox cells and fiducials on each WR-90 RF port. The beamline position of the T53 accelerator section has been fixed from beam dynamics modeling and was set with respect to the outer face of the accelerator coupling cell. The quadrupole triplet alignment in their 80/20 support has been confirmed with magnetic measurement [8] so that the physical pole positions were used to position them in space. Fiducials on the quadrupole triplets were also mapped so that they can be used in the future to align the magnets or other beamline components when beamline pipe is in place and the pole faces are not accessible to the arm probe. The critical test station components were realigned following final assembly of the RF distribution components to insure the accelerator section and gun retain their precise location. It was necessary to measure the accelerator structure and quadruple magnet fiducially because the bore of the magnets and surface of the section were no longer accessible.

Bakeout

The RF gun vacuum system is comprised of: an RF input window; a WR-90 pumpout; the Mark 1 RF gun; a custom weldment cross; an all-metal RF gate valve; a hot cathode vacuum gauge; two 10 L/s ion pumps; two 40 L/s ion pumps; and additional vacuum nipples, T's, blanks, and an all-metal angle valve to connect the major components. After final assembly and alignment of this unit, the entirety of the system excluding the pump magnet housings has been wrapped with heater tape and aluminum foil, and baked to 120°C for over a week. A base pressure of 2 10^{-9} Torr has been achieved.

Baking the completed vacuum system of the beamline and RF distribution will provide the best possible starting point for RF processing and commissioning. The T53 accelerator section, gun diagnostic pop-in and photocathode laser mirror box, as well as the full RF distribution up to the klystron output window form a single vacuum system. The complete system bake was planned using 13 independent heater tape and PID control channels. The system was baked to 100°C for over a week and base pressures of 1–4 10^{-9} Torr was achieved once the system cooled to room temperature.

Conditioning

RF processing of the T53 accelerator section is underway. The control system for critical accelerator diagnostics is in place and tied into the arc detection system that was used for RF commissioning of the XL-4 klystron [7]. The arc detection chassis is active on the klystron forward and reverse, the RF gun forward and reverse, and the accelerator section forward and reverse. In addition the same NI chassis that does the real time monitoring acts as a digitizer for the modulator voltage and current. In order to condition most safely, the accelerator section is being brought to full power first, so that the transport waveguide can be processed and the control system can be debugged.

CONCLUSION

The major components for the X-band test station have been designed, fabricated, installed, and aligned. The XL-4 klystron has been delivered, dressed and installed in the ScandiNova modulator, and tested to full peak power [7, 11]. Assembly of RF transport, test station supports, and accelerator components, final assembly and bakeout have been completed. RF conditioning of the vacuum RF transport, accelerator section, and RF gun is underway. Laser transport for the photocathode drive laser is complete, and the laser system will be brought into operation once the laser safety interlock system installation is complete.

Conditioning is focusing on processing the RF gun to full operating power, which corresponds to 200 MV/m peak electric field on the cathode surface. Single bunch commissioning of the Mark 1 design will provide confidence that this first structure operates as designed, and will serve as a solid starting point for subsequent changes, such as a removable photocathode, and the use of various cathode materials for enhanced quantum efficiency. Charge scaling experiments will follow, partly to confirm predictions, as well as to identify important causes of emittance growth, and their scaling with charge. Multi-bunch operation will conclude testing of the Mark 1 RF gun, and allow verification of code predictions, direct measurement of bunch-to-bunch effects, and initial implementation compensation mechanisms.

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