LLNL X-BAND RF SYSTEM*

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Abstract

An X-band test station is being developed at LLNL to investigate accelerator optimization for future upgrades to mono-energetic gamma-ray technology at LLNL. The test station will consist of a 5.5 cell X-band RF photoinjector, single accelerator section, and beam diagnostics. The high power RF for the test station will be provided by a SLAC XL-4 11.424 GHz klystron driven by a ScandiNova solid-state modulator. The high power system has been installed and results of initial testing into high power loads will be presented. Performance of the system with respect to processing and stability will be discussed as well as future plans for the low level RF system.

INTRODUCTION

Extremely bright narrow bandwidth gamma-ray sources are expanding the application of accelerator technology and light sources in new directions. Mono-energetic gamma-rays enable new features in nuclear applications by tapping into the very narrow unique nuclear resonances of various isotopes [1, 2, 3]. Advancements in nuclear material detection, fuel rod assay, and waste management only begin to hint at the possibilities made possible by this transformational technology. Narrow bandwidth gamma-rays place very stringent demands on the laser and electron beams that interact to produce them. Next generation advancements in gamma-ray production require these demands be satisfied, while simultaneously increasing the average flux of gamma-rays at a specific energy (that is, $N/eV/sec$ at the energy of interest). In order to increase the total flux, the machine currently being constructed at LLNL will operate at 120 Hz, while researching methods to raise the effective repetition rate of the machine to greater than kHz.

As part of the work of using X-band power at LLNL for accelerator applications [4, 5, 6], installation and commissioning of an X-band RF capability [7] has been completed, and is partially reported in this paper.

Modulator

Figure 1: Photograph of ScandiNova modulator, SLAC XL-4 klystron, and high power RF load tree at LLNL.

The high voltage pulse required by the klystron is provided by a state-of-the-art, solid-state high voltage modulator. We have chosen the solid-state modulator (K2-3X) built by ScandiNova for its ability to provide pulse-to-pulse repeatability and flat pulse shape. Better performance from the high voltage modulator insures the highest quality RF output from the klystron. Modular design results in a high voltage modulator that provides a high level of safety due to low (∼1 kV) primary voltage levels. These low voltages also lowers component failures due to reduced thermal and electrical stress. High electrical efficiency allows cooling costs to be approximately half of a line-type pulse forming network modulator. Both peak and average power delivery can be adjusted over time to meet changing system requirements.

Klystron

The high power RF source is an X-band klystron (XL-4) which was developed by SLAC in the mid 90's for the high power testing of the X-band structures [8, 9]. The XL-4 is a solenoid focused klystron which requires a 0.47 Tesla solenoid, capable of producing 50 MW of peak RF power

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for 1.6 μs. The XL-4 klystron has been the workhorse of high gradient testing over the last 15 years, and has been used in: NLC structure testing; NLCTA beam acceleration; generating 500 MW of RF using SLED-II pulse compression; studying breakdown limits of various RF structures, materials, and cavity designs; three successive X-band photogun programs; and increasingly as an energy linearizer for S-band linac-based light sources such as LCLS, and Sincrotrone Trieste.

TESTING

The ScandiNova K2-3X modulator had been tested using a low average power load at low rep rate up to a peak voltage level of $\sim$80 kV. Full testing of the modulator required the proper impedance load for which it had been designed: an XL-4 klystron. The XL-4 tube was dressed and installed into the modulator by LLNL personnel, and connected to the HV output of the modulator. Modifications to the ScandiNova modulator were made based on operating experience including: new low impedance power supply cables, redundant interlocks, and matched tuners to flatten the final high voltage pulse.

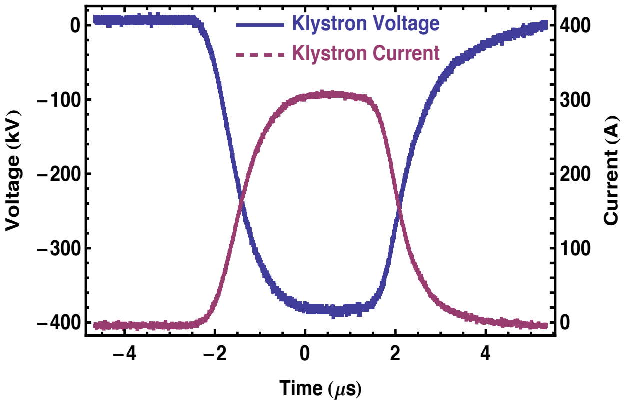

Figure 2: Measured modulator voltage (calibrated capacitative divider) and current (klystron gun current transformer) pulses. 400 ns flat top used for RF generation

The output of the klystron was connected to a -55dB directional coupler to measure the forward power from the klystron, and any power reflected back to the klystron from the loads during conditioning. The load tree consisted of a high power -3dB coupler and three medium average power loads (one for matching and two to share the power load). Vacuum pumping was through the through ports on the loads and mode converter spools on the klystron output window and -3dB coupler. Vacuum level was measured with a hot cathode gauge which was logged. Baking of all components was done at $\sim$120° for several days to achieve low 10^{-8} Torr base pressure.

Arc detection was critical for efficient processing and was implemented using a realtime LabView program. The arc detection software was tested at four simultaneous channels running at 300 Hz and was able to inhibit triggering when test breakdown signals were input. The vacuum response to each shot was visible at relatively high power for a given pressure or initial conditioning level. Pressure buildup led to small (kW level) reflections of power to the klystron, with the majority of signal on the reflected port of the directional coupler coming from load mismatch and coupler directivity.

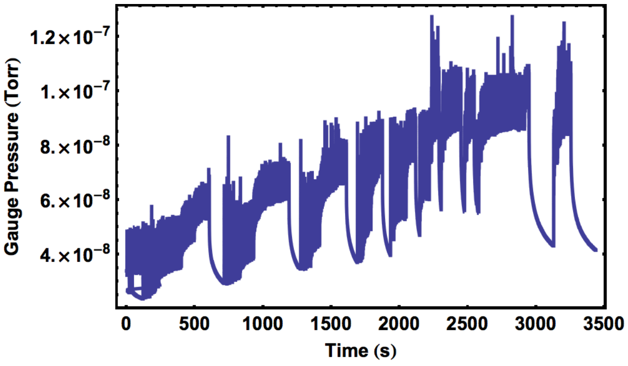

Figure 3: Selected vacuum history of RF processing. Increasing baseline pressure is halted and recovers as arc detection is triggered on small reflections on built up gas.

Processing proceeded over approximately 80 run hours at up to 10 Hz, and a total of $\sim$2.2 million pulses. A final RF power of 50 MW was achieved for 400 ns with very low breakdown rates as detected by the arc detection software. High voltage pulse flatness was measured and observed to be extremely good at 0.05%. The RF pulse flatness was comparable at 0.1%, with some small contribution from the initial low-level RF setup implemented for klystron testing. The shot-to-shot stability of the RF pulse was also extremely good at 0.01%. RF phase stability was measured both by direct mixing and I/Q mixing and was better than $<$0.5°. More detail on these measurement will be available in [10].

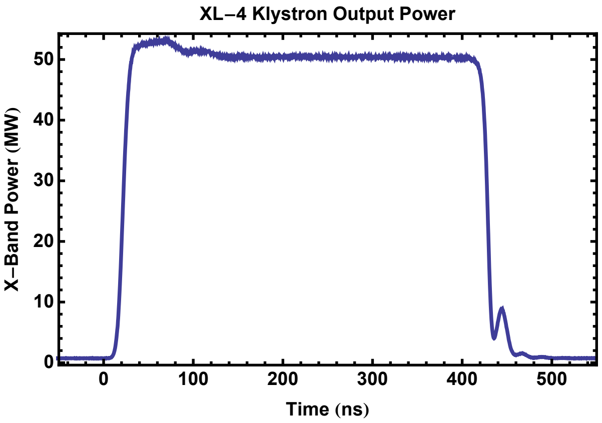

Figure 4: Measured 400 ns RF power pulse. Small reflections observed at start and end of pulse from reflections in the directional coupler and load tree.

CONCLUSION

Initial results of X-band RF testing at LLNL have been presented. The preliminary performance of the system with respect to processing and stability is extremely promising: 50 MW, 400 ns pulses at 10 Hz; HV pulse flatness: 0.05%; RF pulse flatness: 0.1%; RF shot-to-shot stability: 0.01%; RF phase stability: <0.5°. Full installation description, commissioning results, and experimental results will be presented in the future [10].

Commissioning will focus on processing the RF gun to full operating power, which corresponds to 200 MV/m peak electric field on the cathode surface. The gun fill time of 65 ns will only require processing to 200–250 ns pulse lengths. The fill time of the traveling wave structures is 75 ns and the gradient achieved is relatively low with respect to RF conditioning.

The LLRF system for the final configuration of the test station will include: synchronization to the laser for the RF photoinjector, low-level amplitude and phase control, an RF relay to isolate the klystron input, and the TWTa which ultimately powers the klystron. Full implementation of this system is underway and will be partially completed for initial accelerator RF processing, with full implementation to produce an accelerated and high quality electron beam.

REFERENCES

[1] C.P.J. Barty, and F.V. Hartemann, *"T-REX: Thomson-Radiated Extreme X-rays Moving X-ray Science into the"Nuclear" Applications Space with Thomson Scattered Photons"*, UCRL-TR-206825 (2004).

[2] D.J. Gibson, *et al.*, Phys. Rev. STAB **13**, 070703 (2010).

[3] F. Albert, *et al.*, Phys. Rev. STAB **13**, 070704 (2010).

[4] R.A. Marsh, *et al.*, Phys. Rev. ST Accel. Beams, 15, 102001 (2012).

[5] S.G. Anderson, *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A, 657 1, pp. 140–149 (2011).

[6] R.A. Marsh, *et al.*, *"LLNL X-band Test Station Status"*, WEPFI077, *IPAC 2013*.

[7] R.A. Marsh, *et al.*, *"50 MW X-Band RF System for a Photoinjector Test Station at LLNL"*, TUP132, *PAC 2011*.

[8] G. Caryotakis, *The X-Band Klystron Program at SLAC"*, SLAC-PUB- 7146 (1996).

[9] A. Vlieks, *X-Band Klystron Development at SLAC"*, 44th ICFA Advanced Beam Dynamics Workshop: X-band RF Structures and Beam Dynamics, Warrington UK, (2008).

[10] R.A. Marsh, *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A, *in preparation* (2013).