COMPACT X-BAND ACCELERATOR CONTROLS FOR A LASER-COMPTON X-RAY SOURCE*

D. J. Gibson†, R. A. Marsh, G. G. Anderson, C. P. J. Barty,
Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Abstract

LLNL's compact, tunable, laser-Compton x-ray source has been built around an advanced X-band photogun and accelerator sections and two independent laser systems. In support of this source, a complete integrated control system has been designed and built from scratch to provide access to the critical control points and continues to grow to simplify operation of the system and to meet new needs of this research capability. In addition to a PLC-based machine protection component, a custom, LabView-based suite of control software monitors systems including low level and high power RF, vacuum, magnets, and beam imaging cameras. This system includes a comprehensive operator interface, automated and expandable arc detection to optimize rf conditioning of the high-gradient structures, and automated quad-scan-based emittance measurements to explore the beam tuning parameter space. An overview of this system is presented, including the latest upgrades to FPGA-based hardware for the RF system controls.

INTRODUCTION

A compact laser-Compton x-ray source based on x-band accelerator hardware has recently been commissioned at LLNL [1]. While the accelerator was being built and brought online, a remote control system was developed in parallel to run it, with features added on demand as the accelerator grew in complexity and as tasks amenable to automation became apparent. For this control system, National Instruments LabView was chosen as the basis for the bulk of the control system, with PLC logic supplementing it to provide basic IO and machine protection functionality. Other platforms, such as EPICS, were considered but not selected as they generally have a steeper entry curve getting the first devices online with no local experience. Using LabView, basic functionality was able to be provided rapidly. Also, given the relatively small scale of the system, the highly distributed nature of EPICS was unnecessary. Once the platform has chosen and the software grew in complexity, there has not been a need to reconsider that path.

In this paper, we present an overview of the key components of the control system: the RF control chassis, the machine protection system, and the auxiliary support system controls.

* This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
† gibson23@llnl.gov

RF CONTROL AND MONITORING

Low level RF control, and all RF monitoring, is performed using a National Instruments (NI) PXI system running the real-time version of LabView. User interface is provided by a comprehensive front panel (Fig. 1) that communicates with the real time control through a mix of shared variables and network streams. This front panel gives the operator control of:

- the RF system timing (Modulator trigger, travelling wave tube gate, low-level RF pulse trigger) and trigger rate through a Greenfield Technology GFT-9404 delay generator PXi card
- the configuration 12 1-GHz digitizer channels, used for a combination of arc detection and diagnostics
- the configuration of the arc detection algorithms discussed below
- the configurations for various calculations performed on the traces, allowing for monitoring of beam charge, gun gradient, klystron output power, etc., and
- the shape of the low level rf pulse feeding the system.

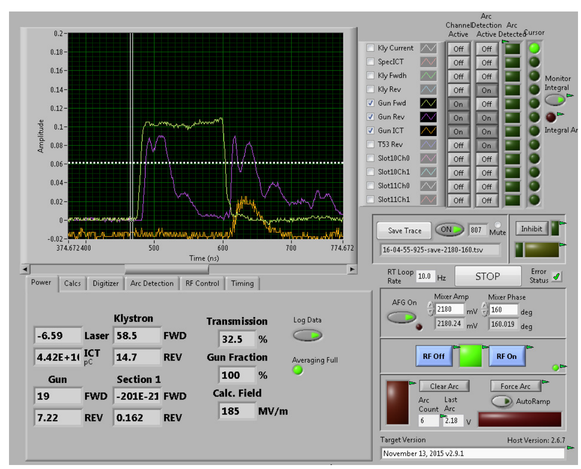

Figure 1: User interface panel for integrated RF controls.

Low-level RF pulse generation

The 11.424 GHz signal from the master clock is modulated by an IQ mixer driven by an Active Technologies AT-1212 2-channel, 14-bit arbitrary function generator (AFG) connected to an NI PXI-7954R board. Currently, a simple square pulse is generated, but once a planned RF pulse compressor is installed, more complicated shaping (such as a phase flip in the signal) will be easily implementable. This shaped pulse is supplied to the traveling wave tube and klystron for amplification to ~50 MW.

The operation of the AFG with the supplied FPGA code only allows 6.4 ns (156.25 MHz) accuracy of trigger-to-output timing, which doesn't meet our requirements. Fig. 2 shows a histogram of the offset of the rising edge of 1000 AFG pulses relative to the mean arrival time of those pulses, allowing us to quantify the system stability. With the provided code, the jitter shows an rms spread of 1.6 ns. To improve this performance requires a few changes. First, we drive the source with a 1/8th frequency (1.428 GHz) clock to synchronize with the accelerator. Although it exceeds the design specification for the AFG hardware, it continues to function sufficiently for our needs. Second, we implemented an input de-serializer in the VHDL code, which allows the FPGA system to monitor the trigger signal at 714 MHz even though the FPGA software runs at only 178.5 MHz. The pulse shape can then be shifted to correct for this trigger phase relative to the main clock, bringing the timing accuracy down to 1.6 ns (measured rms jitter of 0.43 ns). Finally, by generating the master laser trigger at exactly 10 Hz by counting the clock pulses, we ensure the AFG trigger (provided by the laser timing system) always arrives at the same point in the AFG timing cycle, further reducing the trigger accuracy to <1 ns (measured rms jitter of 0.18 ns).

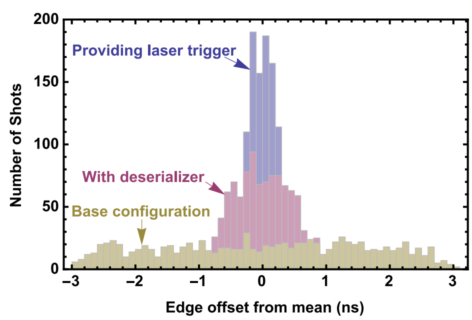

Figure 2: Histogram of 1000 shots for three different triggering options: the AFG software as shipped, adding a deserializer to the trigger input to reduce latency, and providing a laser trigger synced to the AFG clock.

Modulator Control

The klystron is powered by a Scandinova K2-3X moduator, providing 420 kV, 330 A pulses. The modulator is equipped with it's own manufacturer-supplied control hardware, which provides network-based access to all necessary controls and readbacks. This system also controls the klystron solenoid magnets and monitors water flow through the system. The relay-logic based facility personnel safety system ties directly into the modulator, preventing the high-voltage circuits from being energized without a permissive signal supplied by the facility.

A custom interface screen was created in LabView to simplify operator interaction with the modulator and avoid haven't to manually adjust the cathode filament current each time the system was turned on and off. This also allows the built-in LabView datalogging capabilities to monitor the performance of the modulator and keep a log of beam operating time.

Arc Detection

RF power detector diodes monitor transmitted and reflected RF power at the klystron output, the photogun input, and each section input. These signals, along with signals from the integrating current transform and other diagnostics, are fed to a bank of 1 GHz, 8-Bit Digitizers (NI PXI-5154) in the RF control chassis. These traces are available to the user at a rate that depends on the network connection to the interface panel and the other processes on the interface machine; we typically get 1-3 Hz refresh rates for routine monitoring. Based on user configurable parameters, summary data is also presented, such as klystron, gun, and section power, gun gradient, and current charge.

Although not every trace is transmitted to the front end, each of the channels is checked on every shot for signs that an arc occurred. Based on user specifications at the interface panel, this could be either the trace exceeding some trip level within a gated window or the integral of the difference between two consecutive shots exceeding some threshold level. If any channel shows either of these conditions, the chassis inhibits firing of the modulator and low-level RF pulses and alerts the user. In manual mode, the user can adjust the power level, clear the arc error, and resume operations. During conditioning however, generally an "autoramp" mode is used, where the operator configures a waiting period, then a series of ramp speeds to slowly, but automatically, bring the power back up to the breakdown gradient. The system monitors this progress and switches back to manual mode if arcing starts occurring at lower and lower gradients, indicating a problem that needs operator attention.

PLC CONTROLS

In addition to the protection functions provided by the arc detection monitoring, an Allen Bradley SLC5000 PLC system provides machine protection functions This sytem monitors pressure set points on vacuum gauges throughout the system, quickly sealing off the gate valves if an overpressure condition is detected. It also monitors water flow and temperature through the gun solenoid to prevent overheating. The PLC provides a permissive signal to the facility relay logic system, preventing operation of the RF system if an error in any of these key parameters is detected.

The PLC hardware also serves as a general purpose analog and digital I/O device, serving up access to LabView through an OPC server. This system controls the vacuum gate valve, the mechanical popins that insert YAG diagnostic screens into the beam at various points, and monitors the klyston water temperature via several RTDs.

AUXILIARY SYSTEMS

Most of the remaining systems that require operator control are based on self-regulating hardware that provides command-based control via some form of serial or network

ISBN 978-3-95450-147-2

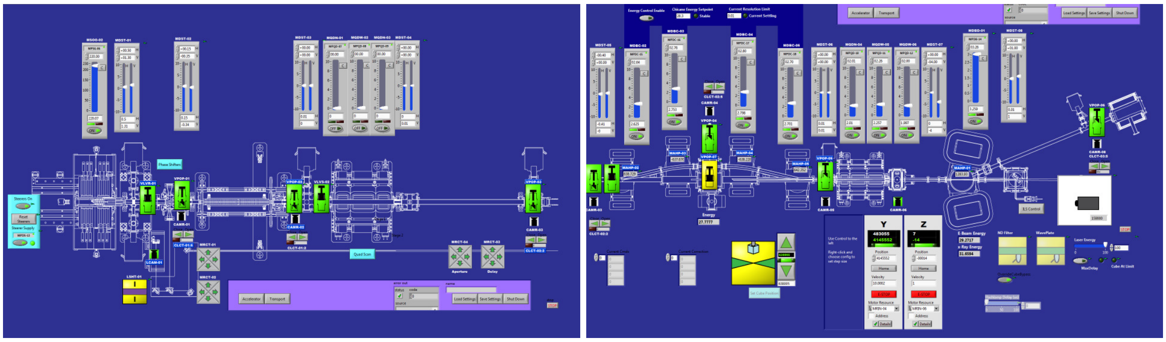

Figure 3: The two main operator screens, providing access to all the key operational parameters.

connection. Serial devices, using either RS-232 or RS-485 standards, are connected to NI serial-to-ethernet adapter boxes, allowing all devices to be accessable from any machine.

In most cases, a "back end" control program deals with the direct communication with the devices, and provides access points, via shared variables, in the LabView environment. This allows multiple front end programs to access the controls (for example, both the main control screen and the automated quad-scan program can control the same quadrupole magnet). For the magnet power supplies, ion pumps, and Gigabit ethernet cameras, all of which have many devices to communicate with, the system was designed to allow the addition of new devices without having to change the basic code, merely to update the configuration with information about the new device, minimizing the need to recompile and redeploy the software as additonial supplies came online as the machine grew. These systems rely on LabView's actor framework to spin up a control channel for each physical communication channel (one for each network or RS-232 device, and one for each RS-485 bus which might have multiple addresses), periodically poll the devices, and report out the current status, as well as respond to commands to change the parameters. Again, because the shared variable architecture is being used, the built-in logging capability can be leveraged to monitor and search for long-term trends in the machine operation.

Smaller scale systems (such as the chillers stabilizing the gun, section, and solenoid temperatures; the stepper motors controlling the RF power distribution and phase and diagnostic positioning; or the digital delay generators providing system timing) have simpler architectures that are hand-built to talk to a specific set of devices. However, since the code is well developed from the systems mentioned above, it's likely that these systems will be moved to the expandable architecture the next time one needs to be updated.

OPERATOR INTERFACE

The main operator interface screen is shown in Fig. 3. This provides access to a single operator allowing control of: all gate valves, magnet currents, RF power balance and section phase, laser alignment onto the imaging aperture and onto the photocathode, diagnostic popins and imaging cameras, interaction point alignment motors and laser motors, laser timing and intensity controls, and x-ray diagnostic positioning. These screens and the RF control screen constitute the majority of operator interaction. Vacuum and magnet system status are displayed on a separate screen, along with the laser and electron beam images and the x-ray camera output for operator feedback (Fig. 4). KVM switching allows the operator to access these machines if needed to correct a problem, but such issues are rare.

CONCLUSION

Routine accelerator operation and x-ray experiments rely on the stability of the control system described here. The architecture has been designed to be easily expandable to add new components or new functionality with minimal disruption. The next developmental step will be to switch the RTOS and digitizer-based arc detection with an FPGA based system allowing intrapulse RF shutoff and expansion to more channels as additional sections are added.

Figure 4: Operator work station, showing 9-screen control configuration, including the three main control screens and 6 system monitoring screens.

REFERENCES

[1] R. A. Marsh, G.. Anderson, D. J. Gibson, and C. P. J. Barty, "LLNL X-band gun results," presented at IPAC' 16, Busan, Korea, May 2016, paper THPOW026.