INSTALLATION OF A HOT-SWAPPABLE SPARE INJECTOR LASER SYSTEM FOR THE SLAC LINAC COHERENT LIGHT SOURCE*

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Abstract

LCLS is a facility for generation of very short duration, highly intense x-ray pulses which requires an extremely reliable photocathode electron source. In order to maintain high uptime (>95%) for the experimenters, operations rely on a maintenance program for active laser components as well as on built-in redundancy in case of failure. To accomplish this, a duplicate laser system was installed, allowing for quick swap between the active system and the spare in the event of a malfunction or for planned maintenance. As an added bonus, this redundant system provides additional possibilities for science as both laser systems can also be run to the cathode simultaneously to create multiple particle bunches. Diagnostics were put in place to maintain both spatial and temporal overlap and allow for the fast switching between systems by operations personnel while still remaining within the safety envelope. This was done for both the primary UV drive laser as well as the secondary IR "heater" laser. This paper describes the installation challenges and design architecture for this backup laser system.

BACKGROUND

The Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory is a high intensity, extremely tuneable X-Ray Free Electron Laser Facility (XFEL). The light this facility uses for experiments is generated by a 1 km electron accelerator with a Photocathode source [1]. Light from a high power 253 nm wavelength (UV) laser (hereon referred to as the Drive Laser) is pulsed at up to 120 Hz on a copper cathode to emit electrons which are then accelerated by RF through a series of cavities.

In order to counteract unintended micro-bunching of the electrons in each pulse, they are also sent through a small chicane with an alternating series of permanent magnets (undulator) where they interact with a second 760 nm (IR) laser called the Heater Laser. To save the cost of constructing a completely separate system for the Heater Laser, it is actually formed from the unconverted light of the Drive Laser during the Tripling process used to create the UV light.

Loss of either of these laser systems due to an equipment failure would result in the unavailability of beam for the end users performing their experiment that week. Two exact duplicate laser systems (named Coherent 1 and Coherent 2) were developed so that there would always a spare available should something break or need to be serviced on the active line. Unfortunately, due to the high maintenance required to keep these lasers tuned up appropriately and the high sensitivity of the XFEL produced downstream to small changes in the characteristics of the injector laser systems, it could take many hours for a qualified laser specialist to switch to the spare, align it on the cathode, and tune it to match the old laser. This issue was compounded outside of the normal Day Shift hours when the specialist would have to drive in to site from home to perform the work.

REMOTE SWITCHING

In order to reduce the high downtime cost incurred by failures or scheduled maintenance tasks on the active laser system, it was desirable to implement a method by which Control Room staff could remotely switch between the lasers quickly. To do this, new mirrors and shutters were put in place in the common line of the Drive Laser and Heater Laser respectively before they entered the transport pipe down into the accelerator injector vault (Figure 1).

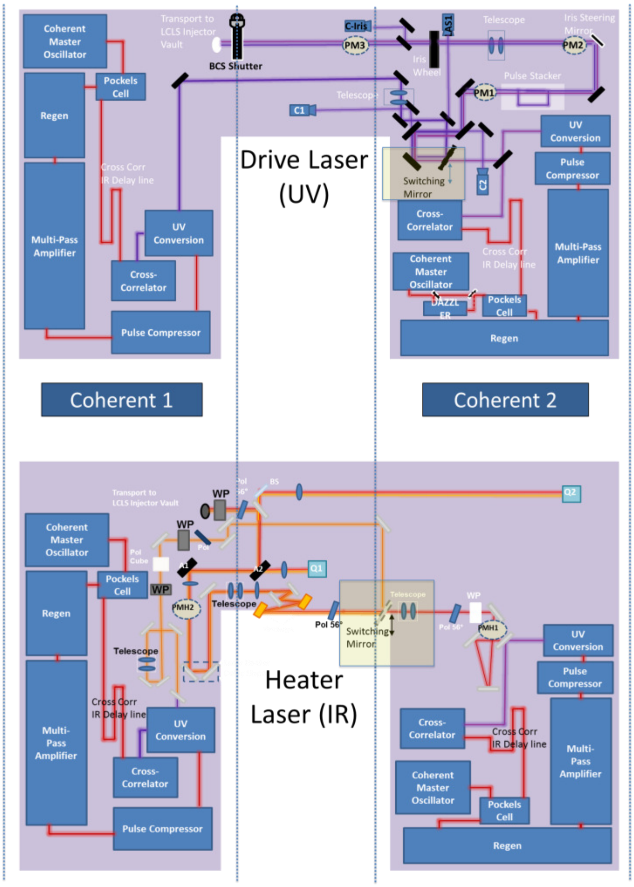

Figure 1: Optics table layout of active and spare injector laser systems.

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The mirror mounts would have control along three axes – transverse tilt control Left/Right and Up/Down for the mirror itself, and longitudinal In/Out on a linear stage to insert and retract the mirror entirely from the laser path. Additionally, two solenoid driven shutters for Drive Laser and two for the Heater Laser would be used to block the unused beams or block both beams while the mirrors are inserting or retracting. These all need to be controlled remotely over the EPICS Channel Access network with automated code to assist in fast switching.

IMPLEMENTATION

For simplicity and to help with maintenance costs we chose to stick with the same or compatible hardware devices already used elsewhere in the laser system wherever possible (Figure 2).

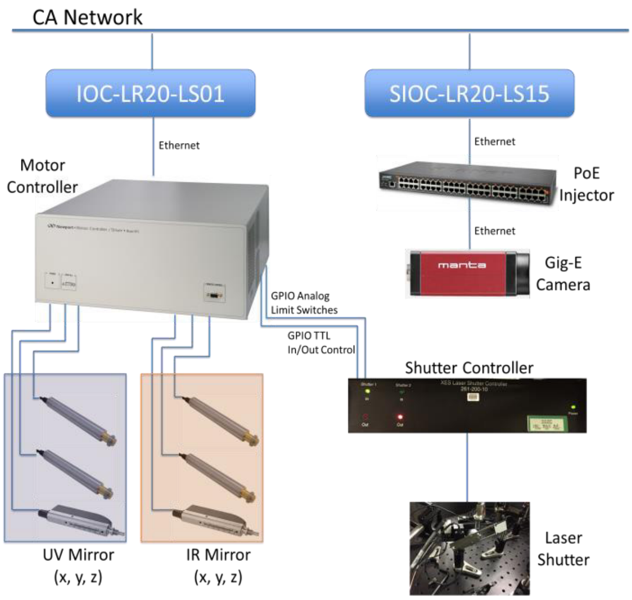


Figure 2: Hardware architecture for installation.

Motion Control

For motor control in the LCLS Laser System we typically use the Newport XPS-Q8 smart motor controller in conjunction with compatible stepper or servo motors also from Newport. We kept to this trend and chose the LTA-HS stepper motor for the In/Out control and used TRA6CC steppers for the transverse steering control.

Shutters

The shutters we use are SLAC built devices consisting of a black high absorption (non-reflective) material on a solenoid driven arm. The fully open and closed positions have photo-interrupter limit switches. Control is managed by a SLAC built controller chassis which provides local status and power for the shutters and can in turn be controlled via TTL output and position switch read back signals. Since we were already using the Newport XPS controller for the mirror motors, it was a simple decision to use the built-in GPIO ports to handle control and read back of the shutters as well.

Cameras

In order to monitor the spatial profile and alignment of the spare laser while not in use, a camera was installed which the Laser Operators can monitor daily and ensure that the spare is in good condition. We used an AVT Manta G033B Gig-E camera with Power-Over-Ethernet (PoE) and the cover glass removed by the vendor to enable use with UV.

A Soft IOC is run on a Dell PowerEdge R620 server where all image processing is done. As raw image data from the camera can require a lot of bandwidth, the cameras are run directly to the server on a local DHCP managed IP address before being processed down and set out over the Channel Access network. A Planet HPOE-2400G PoE Injector is used between the camera and the server to provide power to the camera.

TWO-BUNCH CONSIDERATIONS

In addition to the primary goal of fast remote switching between the two laser systems, it was also desired by the physicists to allow for both lasers to be run simultaneously separated slightly in time. To accomplish this, the switching mirrors are replaced with beam splitters which are left in place and the shutters alone select which beam (or both) is allowed down into the injector vault. The time delay can be adjusted either by varying the EVR trigger delay one of the laser's RF phase-lock-loop (PLL) or by using the existing motorized delay stage in the pulse stacker.

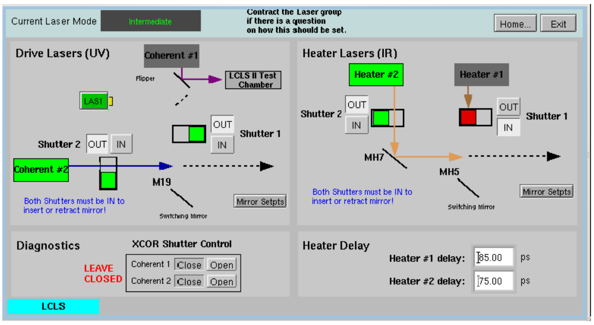
Safety

The Beam Containment System (BCS) safety system uses toroids to measure the electron beam current at various points along the accelerator and trips off the machine if it measures losses exceeding the limits allowed by the Radiation Safety group. These toroid comparators use gated ADCs and to ensure that they do not miss the beam, photo-diodes in the laser are required to measure the laser pulses within a timing gate shared with the toroid comparator system. If the laser falls outside of this 40 ns wide gate, the beam is shut off.

With the addition of a second laser pulse it was necessary to ensure that this photo-diode system could see both pulses and act to make sure that they both fell within the timing gate. As long as both pulses were contained within the 40 ns gate we found that the toroids would successfully average over them both to give an acceptable measurement of the total beam losses.

SOFTWARE

All hardware for the project is controllable through EPICS R3-14-12 with an EDM gui interface (Figure 3). Position setpoints both for the In/Out positions and steering are saved for each laser and can be changed by Laser Operators to compensate for alignment differences between each laser line.


Current Laser Mode: Intermediate

Contract the Laser group if there is a question on how this should be set.

Both Shutters must be IN to insert or retract mirror!

Both Shutters must be IN to insert or retract mirror!

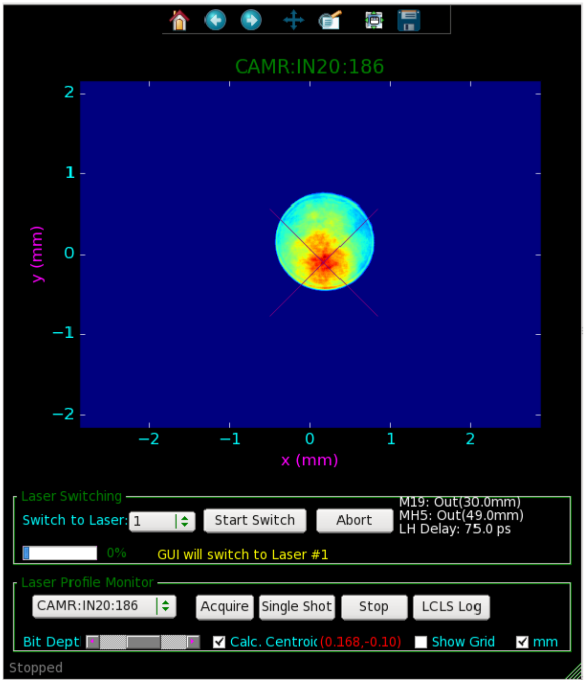
LEAVE CLOSED

Heater #1 delay: 85.00 ps

Heater #2 delay: 75.00 ps

Figure 3: EDM switching interface.

An additional PyQt4 application was also written in cooperation with the control room Operators to provide an automated interface to load and change parameters when switching between lasers (Figure 4).


Switch to Laser: 1

M19: Out(30.0mm)
MH5: Out(49.0mm)
LH Delay: 75.0 ps

0%

GUI will switch to Laser #1

CAMR:IN20:186

☑ Calc. Centroic (0.168,-0.10)

☐ Show Grid

☑ mm

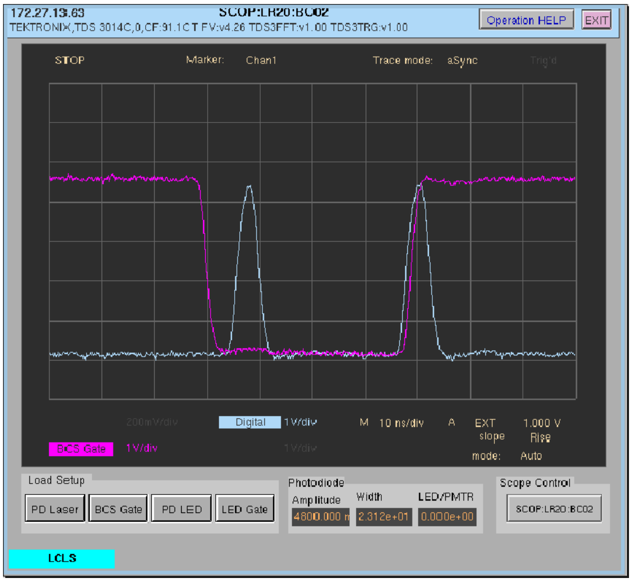
Stopped

Figure 4: PyQt4 Switching Interface. Camera image shows the laser on the virtual cathode after the switching mirrors to ensure that beam is aligned properly.

CONCLUSION

With the old laser setup, switching lasers in the event of a failure would often take several hours. With the new remote switching controls in place however, the Control Room Operators have successfully managed to perform the switch on many occasions in less than 15 minutes. This drastically reduced the downtime incurred by laser equipment failure as well as allowed for more opportunities for the Laser Operators to request that the lasers be swapped so that they may perform scheduled maintenance which in turn has improved the long term performance of the injector laser system as a whole.

We have also now had several experimental shifts running with the new two-bunch operation mode [2] and have successfully seen both laser pulses within the BCS timing gate (Figure 5).


172.27.13.63 SCOP:LR20:BC02

TEKTRONIX,TDS 3014C,0,CF:91.1CT FV:v4.26 TDS3FFT:v1.00 TDS3TRG:v1.00

STOP Marker: Chan1 Trace mode: aSync Trig'd

200mV/div Digital 1V/div M 10 ns/div A EXT slope 1.000 V Rise

BCS Gate 1V/div 1V/div mode: Auto

Photodiode Amplitude 4800.000 m Width 2.312e+01 LED/PMTR 0.000e+00

Figure 5: BCS Timing Gate on oscilloscope. Magenta trace shows the toroid timing gate and the blue trace shows the two laser pulses.

Having proved that the Toroid Comparator system is able to integrate across both beams simultaneously and trip the beam appropriately in the event of losses, we were approved to use this technique to create XFEL for experiments. Taking the light emitted in the Undulator Hall from the two bunches through the into the FEE diagnostic area showed that we were indeed able to lase on both bunches separately by ionizing gas and reading out the scattered particles on PMT detectors (Figure 6).

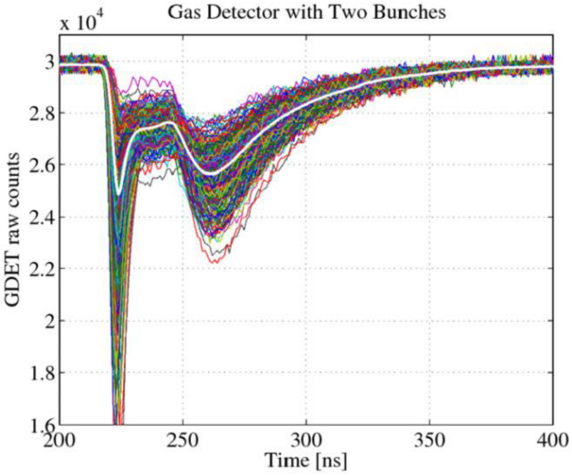


Figure 6: Gas Detector raw waveforms (above) show a 2.5:5 ratio after the laser heater was timed for the first bunch. The spike in the front is an instrumental reaction to coherent synchrotron radiation. Therefore the integrated GDET signal typically uses the counts from 250 to 400 ns.

The two-bunch XFEL was also taken to one of the user hutches where they were imaged hitting a single injected water droplet simulating the use case for experimentation (Figure 7).

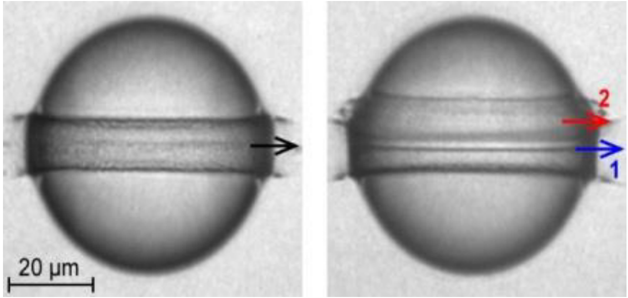


Figure 7: XFEL beams imaged by camera in CXI experimental hutch hitting water droplets. Single bunch beam is seen on the left and two-bunch on the right. The arrows indicate the XFEL beams.

ACKNOWLEDGMENT

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[2] A. Marinelli, et al., “High-intensity double-pulse X-ray free-electron laser”, Nature Communications, March 2015, http://www.nature.com/ncomms/2015/150306/ncomms7369/full/ncomms7369.html?WT.ec_id=NCOMMS-20150311