Overview of Control System for Jefferson Lab's High Power Free Electron Laser

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Abstract

In this paper the current plans for the control system for Jefferson Lab's Infrared Free Electron Laser (FEL) are presented. The goals for the FEL control system are fourfold: 1) to use EPICS and EPICS compatible tools, 2) to use VME and IndustryPack (IPs) interfaces for FEL specific devices such as controls and diagnostics for the drive laser, high power optics, photocathode gun, and electron-beam diagnostics, 3) to migrate Continuous Electron Beam Accelerator Facility (CEBAF) technologies to VME when possible, and 4) to use CAMAC solutions for systems that duplicate CEBAF technologies such as RF linacs and DC magnets. This paper will describe the software developed for FEL specific devices and provide an overview of the FEL control system.

1 Introduction

Jefferson Lab is building an FEL based on superconducting radio frequency (SRF) technology developed for CEBAF. The machine will produce 3-6 μm laser light using a 350 kV continuous wave electron beam from a photocathode gun that is bunched into 0.5 psec rms bunches and then accelerated to 10 MeV in the injector. After passing through a 32 MeV linac the electron beam is accelerated to 42 MeV. The 42 MeV electron beam passes through a wiggler magnet to produce photons that lase using a pair of mirror boxes located upstream and downstream of the wiggler. The laser light is extracted and transported to the user labs for experiments. After passing through the wiggler, the 42 MeV electron beam is recirculated through two arcs which deliver the beam to the entrance of the 32 MeV linac approximately 180 degrees out of phase with the injected electron beam. The 32 MeV linac extracts 75% of the energy from the recirculated electron beam and reuses the energy to accelerate the injected electron beam. The energy recovery scheme reduces RF power requirements, waste heat, and radiation [1, 2].

This paper focuses on the software part of the control system. First an overview of the control system layout is given followed by a brief description of control system procedures, and finally descriptions of FEL specific devices will be presented. Although the control system hardware is mentioned in this paper, another paper presented in these proceedings provides a more in depth discussion of the FEL control system hardware [3].

2 Control system overview

The FEL control system uses the Experimental Physics and Industrial Control System (EPICS) [4, 5] which follows the standard model for accelerator and storage ring control systems. Initially, the FEL requires nine EPICS input output controllers (iocs) in individual VME crates. The operator interfaces (OPIs) will run on five Hewlett Packard (HP) B class workstations and two HP X-terminals distributed across two control rooms in two buildings, the Laser Control Center (LCC) in the FEL building and the CEBAF control room in the Machine Control Center (MCC). High level applications such as slow feedback and emittance measurement packages will also run on the workstations. There are an additional six HP 715 workstations for the six user labs in the FEL. Two HP D class file servers resident in the FEL service the workstations, X-terminals, and iocs. The final operational FEL configuration calls for monitor and control for all systems from the MCC which will simultaneously monitor and control CEBAF. During FEL commissioning and for daily operations tasks related to high power optics control and photon-beam delivery, control will be performed in the LCC. The FEL computers and iocs are isolated from CEBAF systems on an FEL controls subnet.

The nine iocs are located outside the beam enclosure in the FEL building. Eight of the iocs are dedicated to device control. One ioc is dedicated to cryogenic controls for the liquid helium for the SRF cavities while the other seven perform device control for FEL hardware such as the photocathode gun drive laser, high power optics, linacs, magnets, beam diagnostics, vacuum, and timing system. The ninth ioc is not directly used for device control. It will be used to provide FEL system status information for comfort screens for the FEL operators and users.

Four systems use CAMAC since they mirror CEBAF machine systems. Two of these, cryogenics and magnets, are exact duplicates requiring no new software development beyond replication for the FEL components. The other two systems are the four channel beam position monitors (BPMs) and RF. Because of FEL design requirements such as wider vacuum chambers, affecting BPM sensitivity calibrations, and increased energy gains per RF cavity, affecting the RF system, these two systems require some software development to support FEL operations.

Most of the devices for the FEL interface to EPICS through VME modules or GreenSpring IPs through a stand-alone operating system developed at Argonne National Laboratory (ANL) called HiDEOS [6] running on a slave CPU in the VME crate. Systems using VME modules include vacuum, drive laser components such as the drive laser attenuator, pulse controller, and electro-optical (EO) system, beam profile monitor, photocathode gun high voltage, video digitizer, machine protection, and switched electrode electronics (SEE) BPMs.

HiDEOS is used heavily in the FEL. Four HiDEOS CPUs are scheduled for use for interfacing to several IPs. All GPIB devices in the FEL interface to EPICS using IP-488s with the EPICS GPIB common device support and the IP-488 HiDEOS support [7]. Serial communications through HiDEOS use IP-Octal support from ANL. At Jefferson Lab, HiDEOS support for IP-Digital 48, IP-Relay, and IP-16ADC has been developed and interfaced into EPICS for beam diagnostic and laser control and readback. The HiDEOS support developed for the FEL was tested and found to be very reliable during early commissioning FEL photocathode tests.

The control system file structure on the FEL servers and workstations mirrors on a smaller scale that of the CEBAF machine. With a resident duplicate version of the file system as opposed to accessing the CEBAF machine file system via NFS, the FEL is guaranteed quick response times and independent operations. It is possible to run the FEL without interruption while the CEBAF machine file system is down for maintenance activities and vice versa.

The file system consists of three disks. One disk is used for storing FEL archive data. A second disk is for FEL experimenter user accounts, OPI screens, tcl tools for operations, high level applications, high level application support packages, and BURT (an EPICS parameter save and restore utility) files for ioc hourly saves and FEL machine configurations. The third disk is for UNIX executables for EPICS tools such as MEDM (an EPICS OPI), data archiver, and archive data viewer; ioc databases, object code, and boot files; and the electronic logbook.

In addition to carrying over the file system, procedures associated with modifying the CEBAF control system are applied to the FEL. These procedures include versioning software, documenting rollback positions, documenting changes in operations logs, and scheduling test and installation time in coordination with operations personnel. These procedures lead to a more stable operating environment because reliable operations is the goal at every step [8].

3 FEL devices

By now it is clear that the FEL uses many CEBAF standard devices. In addition to these devices, the FEL has unique needs for its laser systems, photocathode gun, and beam diagnostics. Some of these systems are discussed in this section.

3.1 Optical devices for drive laser and high-power optics

The drive laser is used to generate electrons on the photocathode of the gun to produce the FEL electron beam. This laser is located upstairs in the FEL building in an isolated clean room. The pulsed laser light is transported from the clean room to the gun downstairs in the beam enclosure using a series of adjustable mirrors. The drive laser consists principally of the drive laser, the drive laser pulser, and modulator.

The drive laser itself is controlled via RS-232 using an IP-Octal under HiDEOS. The drive laser software provides control for the laser, laser shutter, and laser power. Laser status is updated at a 1Hz rate. If the laser is not working correctly, warning messages are displayed on the laser screen. The RS-232 link between HiDEOS and the laser is monitored. If the communication is lost, a sequence program tries to restore normal communication.

Pockel cells are used for the drive laser EO system. Three EO modulators and an RF amplifier are used to control the polarized beam pulses obtained from the FEL drive laser. Together, they allow a user to modulate the beam power output and to select out beam pulses. An EPICS application provides single point control for this equipment by controlling the power supplies to the modulators; the RF amplifier is controlled through a pin diode which provides 0-60 dB of signal attenuation. Communication with these devices is through a DATEL DVME 628 D/A board, with voltage readback from a VME Microsystems International Corporation VMIVME-3122 A/D board.

The high power optics are used in the lasing process and for transporting the FEL laser beam from the beam enclosure to the user labs in the FEL building. The high power optics consists of a series of adjustable mirrors.

The optics used in the lasing process require alignment of gimbal mount mirrors in the optical cavity. Two 6" optical mirrors are used to focus the laser beam in the wiggler cavity. Each of the mirrors may be moved in yaw and pitch by controlling high precision stepper motors, one for each axis of motion. In addition, a fifth stepper motor is used to control the distance between the motors. The mirrors may be moved in steps of approximately 10 microradians of angle, or several microns of linear distance. Because it is necessary to obtain absolute mirror positions, each of the mirrors is tracked using linear variable differential transformers (LVDTs) capable of accuracies on the order of several microns. The stepper motors are controlled using an Oregon Microsystems card in conjunction with Epics steppermotor records, and the LVDT positions are read from a Highland Technology Model V550 VME card. In addition to implementing motion commands, the software also uses the mirror positions to calculate the cavity modes at the wiggler center; conversely, given a set of cavity modes, the software will automatically position the mirrors to achieve these modes. Future upgrades will implement an autolock feature which will use a PID loop to keep the mirrors positioned without operator intervention. Capability exists to save mirror positions on a periodic basis and when indicated by the operator. Thus, in the event of system crashes, the mirror alignments are restorable. A related application for these mirrors allows the operator to insert pellicles or viewers into the beam, and also to control lamps for these viewers. This capability allows the user to immediately see the effects of repositioning the gimbal mount mirrors.

Picomotors are used in the laser beam transport system. The picomotor application allows single point control of all FEL picomotors, currently 9 total. These motors are used primarily to make small positional changes in various mirrors used for beam transport. One motor controls the motors are two-axis units, but there are also single and triple axis motors. The software controls each of the motors through a New Focus 8732 driver, capable of handling up to 24 single-axis, or 8 three-axis motors in the present configuration; additional slots can hold connectors for up to 48 additional axes. The 8732 driver has a GPIB interface. Individual motors are addressed by setting a slot/connector/channel in GPIB; all subsequent commands are taken to apply to that particular motor/axis, until the address is changed.

3.2 Photocathode gun high voltage controls

This software controls a 500 kV power supply used for the photocathode gun. Communication with the power supply is through a DATEL DVME628 D/A card and an IP-Digital 48, with status and voltage and current readbacks coming through a VMEVMI-3122. The software calculates a ramp to safely bring the voltage up to the level desired by the operator without electrical arcing. It does this by using a ramp which increases the voltage proportionally less as the setpoint voltage is approached, and by reading back the current and pausing in the ramp whenever the current exceeds a threshold value.

3.3 Beam diagnostics

Examples of beam diagnostic devices in the FEL are optical transition radiation beam viewers, stripline and button beam position monitors, multislit beam emittance measuring devices [9], coherent radiation bunch length monitors, and synchrotron light cameras for measuring the beam profile at high average power. Most devices have update rates faster than one second.

From the controls viewpoint, the beam viewers are invoked when a particular camera in the FEL is chosen for viewing. An associated viewer foil is inserted in the beam and the video output from the camera is automatically switched to a TV monitor in the control room. Normally, the video output is not analyzed further. However, by digitizing the video image with a Datacube MaxVideo image processing VME card, many beam analysis functions (e.g. finding beam centroids and profiles) may be performed at a rapid rate. Such functions are also used to analyze data from the multislit beam emittance measuring devices and the synchrotron light cameras.

The video connection system allows video or other types of signals to be connected to TV monitors, oscilloscopes and similar display devices. The basis of the system is an Analog Devices AD8116 crosspoint connection card which can connect up to 16 inputs to any of 16 outputs. A custom chassis was developed which stacks 4 of these cards, so that any one of 64 inputs can be connected to any of 16 output monitors; additional chassis can be added to the length of the drive laser optical cavity. The majority of the system, so that a very large number (up to 4096) of inputs can be connected to the basic 16 monitors. Also, a single input can be connected to more than one monitor. This flexibility is achieved by making the AD8116 cards individually addressable; connection commands are then sent to all cards, but only the card being addressed will act on the command. All the chassis are addressed by a single custom digital I/O card, which is controlled by an Epics video connection application.

4 Conclusion

Jefferson Lab's FEL is nearly complete and commissioning activities have begun. The EPICS control system is supporting commissioning activities. All nine iocs, file servers, and some of the workstations are on-line with the balance becoming operational in the near future. Software discussed here is in use at the FEL with revisions related to operations experience to follow. The software schedule closely follows the commissioning activities with FEL first light in the spring and energy recovery in the summer of 1998.

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