Control System for a High Average Power Free Electron Laser

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Abstract

A high-average-power infrared free-electron laser [1] (IRFEL) capable of continuous kW-level operation at 3 - 6 µm, is being commissioned at Jefferson Lab in Newport News Virginia, USA. The IRFEL is located on the site of the CEBAF machine and is capable of being controlled from either the CEBAF Main Control Center (MCC) or from the local Laser Control Center (LCC). The plan is to control all functions of the electron-beam transport from the MCC except the final steering through the wiggler. All high-power-optics control and photon-beam delivery will be done from the LCC. The control system is based on EPICS (Experimental Physics and Industrial Control System) which is used at CEBAF. The IRFEL control system is roughly 1/10 the size of the CEBAF system. This paper will focus on new systems and describe the hardware implementation. Documentation for the systems can found at http://www.jlab.org/FEL A paper devoted to the FEL software is being presented at this conference by A. Hofler et. al.

1 Introduction

Jefferson Lab's FEL is pictured in Figure 1. It is a kW-level FEL comprising a 10 MeV injector and a 32 MeV linac to produce a 42 MeV, 5 mA CW electron beam for use in lasing. The wiggler extracts about 0.5% of the electron-beam energy, thereby producing kW-level light to user laboratories collocated with the FEL. After lasing, a high-acceptance lattice transports the electron beam back to the linac for deceleration down to 10 MeV to a dump. Thus, 75% of its energy is put back into RF power for use in accelerating other electrons, thereby reducing RF power requirements. It also reduces waste heat and radiation, permitting use of a compact beam dump of uncomplicated design.

The injector comprises a 350 kV dc photocathode gun driven by a commercial Nd:YLF laser. The gun is followed by a copper buncher cavity and a CEBAF-type 1497 MHz SRF cryounit raising the beam energy to 10 MeV. The accelerator uses a full CEBAF-type 1497 MHz SRF cryomodule to generate an average accelerating gradient of 8 MV/m, boosting the beam to 42 MeV energy. Two commercial 50 kW klystrons power the injector's cryounit.

The control system for the FEL was designed and implemented to take advantage of both the operational experience of CEBAF and the decreases in cost of computing power and increasing availability of VME based interface boards. The philosophy for the design was to move out of CAMAC and into VME where possible; low risk for the short construction cycle, but to leave open a clear path for future upgrades.

2 Server computers

The FEL Facility control system is implemented on a private IP subnet to provide isolation from other JLab controls and other networks. The system consists of dual, HP D-250 servers, (figure 2) several console workstations, x-terminals, VME-based data acquisition nodes, printers, etc. These systems are interconnected using a combination of 10Mbit and 100Mbit Ethernet, running over fiber and category-5 cabling.

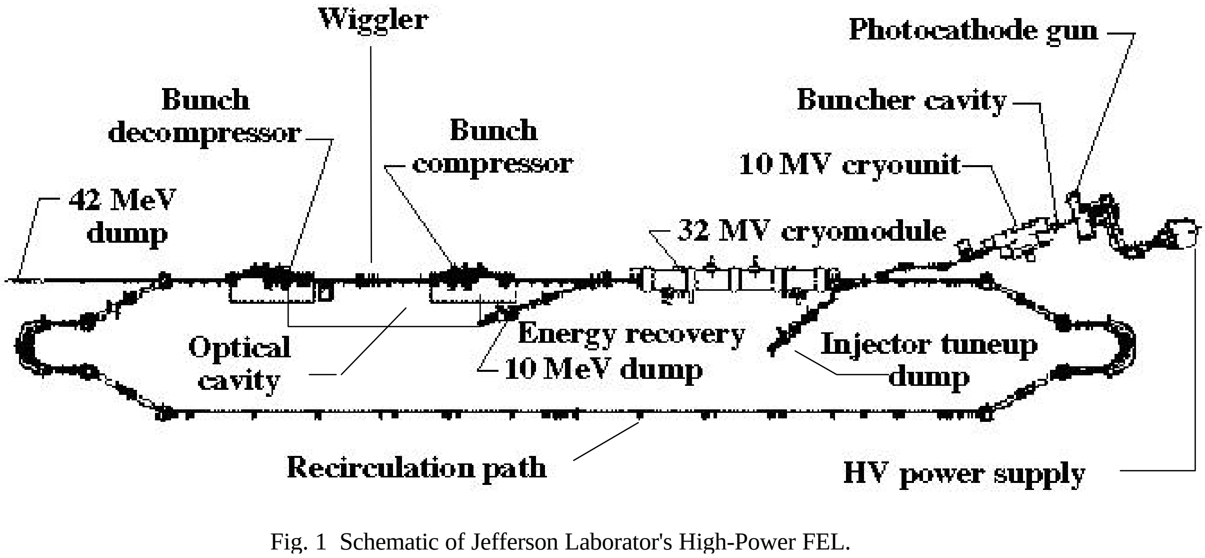

Fig. 1 Schematic of Jefferson Laboratory's High-Power FEL.

The dual servers run a suite of HP products that provide for auto-failover, disk mirroring, system monitoring, load management, etc. As with other Jefferson Lab controls, the servers are designed to host mission-critical applications and services, while operator workstations are generic and can be replaced quickly and easily in the event of failure. The dual server configuration also provides a mechanism whereby system maintenance can be performed without incurring system downtime. The entire server system is fully redundant. Each system unit is provided with multiple FWD SCSI interfaces for root and data disk volumes and associated mirror volumes, multiple network attachments are provided, and all components are provided with uninterruptible power. A "heartbeat" connection is provided between the servers allowing each to monitor the health of the other (note: the LAN is used as fallback in the event of failure of this heartbeat). In the event that a server detects a failure of one of it's own components, alternate interfaces are selected as needed to maintain service. In the event of failure of an entire server system unit the alternate server starts the necessary services locally. Additional system level information can be found at the web site http://devweb.cebaf.gov/acce/Network/FELDescription.html.

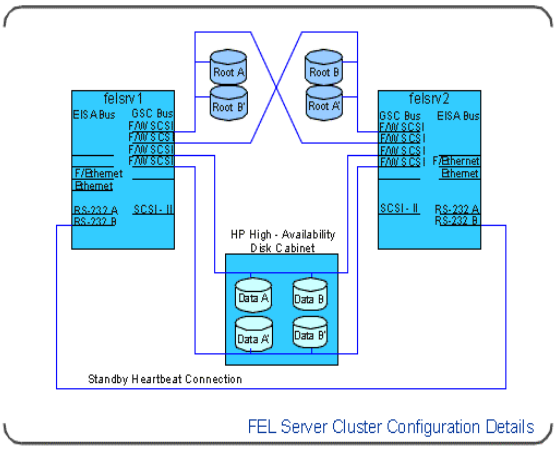

Fig. 2 Server Configuration.

3 Control room

The first electron beam in the new building was drawn off the photo-cathode on September 29, 1997. The initial commissioning will continue from the FEL control room. The control room is modeled from the APS control room, except a smaller version. There are three tables arranged in a broken circle, each table has two work areas. These work areas support either HP workstations or, for the optics table, a workstation and a PC to run the Spiricon Laser beam analyzer.

Each table has a patch system that allows any of 128 analog signals to be connected to the eight 50 ohm BNC ports or any one of the 64 video channels to the four 75 ohm video ports. There is a scope and two 9 inch monitors on two of the tables and a 20 inch color monitor on the third table. Additionally there is an LCD projection display which can project either of two VGA inputs or one RS-170 video signal. This 70 inch diagonal display has proved to be very convenient to monitor the drive laser photo-diode output (via Tectronics TDS 784 scope′s VGA output) or to display a beam viewer. The Viewsonic LCD projector also enables full remote control of a PC with the IR remote control.

4 Operator consoles

FEL consoles are implemented using mid-range HP desktop workstation systems. These systems are all running HP UX 10.20. The installation, configuration and management of software on these nodes is done using HP's "software depot" and "Ignite" software. These nodes are generic, each having essentially identical root volumes. In the event of failure of any of these nodes, the entire functionality can be provided by readily available alternates. Using the automated tools, new systems can be constructed in the lab from scratch -- including application of security and operational patches within a couple of hours, with little or no operator intervention. The long-term plan calls for the deployment of 2 operator consoles within the FEL control room, with two additional installed in the primary Accelerator control room. In addition, two x-terminals are used to provide access to controls from within the clean room and optical controls room.

In addition to the mid-range operator console workstations, a number of workstations are provided within the user labs. These are entry-level workstations, configured and managed similarly to the operator console workstations. During commissioning these workstations are used as supplemental consoles throughout the facility to aid in commissioning.

5 IOCs

Several Motorola VME-based CPUs are used as IOCs within the system, all running VxWorks 5.2. These nodes receive boot and file services from the FEL server cluster, and connect to the network using 10Mbps ethernet. Each beamline ″zone″ has a dedicated bridged segment for it's associated IOCs.

6 Network

The FEL network implements a mix of 10/100BaseX. A Fore Systems Powerhub 6000 acts as a "workgroup switch", providing multiple 10-base and 100-base segments. Routing for the FEL subnet is currently provided by the controls hub in the MCC, but will eventually migrate to the FEL hub. This migration will allow for implementation of a virtual LAN ``backbone" carrying FELNET as well as CTRLNET (Accelerator Controls) and CRYONET (Cryogenic Controls) to all three of these sites. Thus, nodes can be placed into any of these three physical locations while maintaining logical attachment of any of these subnets.

7 Drive laser pulse control

The Drive Laser Pulse Control (DLPC) was developed for control of the photo-cathode drive laser. The pulse control electronics enable full duty cycle control from 100% to less than 0.02% while holding the charge per bunch constant. A system level block diagram is shown in Figure 3. The space charge dominated optics in hte injector require that the charge per micropulse be between 60pC and 135pC for clean transmission and lasing.

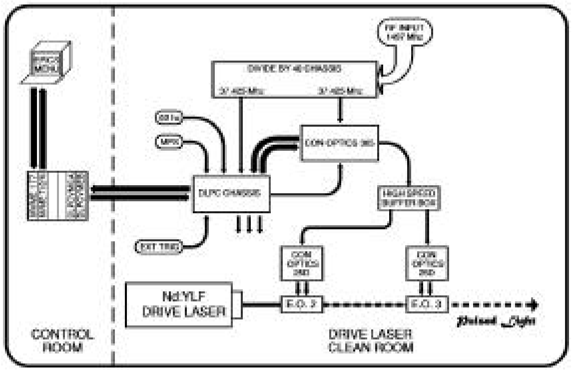

Fig. 3 Block Diagram of Pulse Control Electronic.

8 Video and analog distribution

The Analog Devices 16 X 16 cross-point switch AD8116 was chosen to implement the 64:16 video distribution system and the 128:16 Analog Monitoring System (AMS). We have designed the system using the development board available from Analog Devices. Four of these 16 X 16 boards are mounted in a single chassis, one chassis provides for the video control and two chassis are required for 128:16 AMS.

9 Pegasus TEC camera

The Pegasus CCD camera is going to be used to image the synchrotron light emitted from the electron beam in the bend magnets. This camera uses a two stage thermoelectric cooler (TEC) to reduce the background noise resulting ion an increased sensitivity. The CCD is cooled to -30°C.

This camera uses a 658H x 496V Frame Transfer type CCD with a storage area equal in size to the image area or about 0.5 Mbyte. An interface board is currently under development to interface to the EPICS control system.

10 Stepper motor control

There are two hardware implementations for stepper motor control in the FEL; Highland Technology CAMAC boards and Oregon Micro Systems (OMS) VME-44. The high power RF tuner control hardware was adopted directly from the CEBAF application. All other applications utilize the OMS four channel VME motor controller.

The OMS system was chosen because it had been used at Los Alamos by members of the EPICS collaboration. The FEL I&C group has packaged four motor drives and motor power supply in a chassis combined with an auxiliary power supply in a single chassis. A breakout board has been produced to convert the P2 connections to two "D" connectors; one for connections to the motor driver chassis and one for connections to shaft encoders (not currently implemented).

The driver chassis can be configured with any of the three motor drives available with current per phase variable from 0.2 Amp to 14 Amps, the MD10A and MH10 drives can be operated at 1 or 10 microsteps per step. The MD125 can be operated at 10, 25 50, and 125 microsteps per step for a maximum of 25,000 microsteps per revolution.

11 Insertion device control

These insertion devices require 24 Volt DC power to actuate and provide 24 Volt DC status signals. These devices include the beam viewers, optical shutters, flip-in mirrors and lenses, and the ON/OFF control of the gun power supply. A 12 channel interface chassis was designed to work with the IP-Digital48. This chassis provides 48 optically coupled lines of I/O; two bits of drive and two bits for status for each of the 12 channels. The beam viewers use drive bits for insertion solenoid and lamp power, and the status bits for inserted/retracted status.

The Green Spring Computers IP-Digital48 is used as the interface to the control system for 24 Volt DC devices. Each Industry Pack uses one of the four available daughter board slots on the Motorola MVME 162 VME module. HiDEOS is required when using the MVME 162 for I/O operations.

Acknowledgements

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References

[1] L. Bohn, "Recirculating Accelerator Driver for a High-Power Free-Electron Laser: A Design Overview", in Proc. 1997 Particle Accelerator Conf., Vancouver, BC, 12-16 May 1997 (in press).

[2] A.S. Hofler, A.C. Grippo, M.S. Keesee, and J. Song, "Overview Of Control System For Jefferson Lab's High Power Free Electron Laser", This Conference.