R&D ERL: Controls System

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Abstract

This paper examines the equipment and software from which the controls system interface for the Energy Recovery Linac (ERL) will be implemented at the Brookhaven National Laboratory.

1 Magnet/Power Supplies (electron beam steering and focusing)

Steering and focusing of the electron beam will be performed using magnets and power supplies that are controlled through several different DC power supply interfaces, each supporting 16 bit sampling of setpoints and readbacks and monitoring of power supply statuses.

The IE Power 35V/320A Main Magnet Power Supply will use one VME power supply controller module for reference control, readback of statuses, and digitized power supply readbacks. The PSI includes 4 16-bit DAC modules at +/-10V, 16-bit reference control at +/-10V, and digital inputs and output generators. All I/O from the VME module to the power supply interface is carried via optical fibers in order to maintain electrical isolation. The local power supply interface handles the digital to analog conversion of reference signal, and the digitization of all status and measurement readbacks. The software interface for the VME module is used routinely for other projects.

A total of 34 bipolar 15V/10A Danfysik SHIM power supplies will be controlled via an RS-232 or 485 interface. LINUX server-based software will be developed to provide the user interface to each device, including status control and readback, and DC setpoint control. These supplies will power dipole, quadrupole, combined-function, and solenoid magnets.

Five Kepco 50V/20A bipolar power supplies will use an RS-232 interface using LINUX server-based interface software that will be developed. These supplies will power solenoid and chicane magnets.

A BiRa bipolar 50V power supply interface (6x6A, 32x2A, 38 total) will consist of two VME DAC boards (38 of 64 total channels used) for synthesis of analog references and one VME 16-bit ADC board (38 of 64 channels used, 100kHz maximum total scan rate) for readback signal digitization. Each BiRa crate incorporates one TTL status output and one TTL interlock input signal for all 16 power supply modular interface cards mounted therein, requiring the use of a total of one VME digital output board (3 of 32 channels used) for status control and one VME digital signal input board (3 of 32 channels used) for crate status readbacks. The software interface is used routinely for other Collider-Accelerator projects. These supplies will power dipole, quadrupole, corrector, combined-function, air coil, and chicane magnets.

If the RS-232 interface option is used where available, a total of 39 upstream serial ports will be needed to support all of the power supplies using a serial interface. If RS-485 is used for the Danfysik units, a total of 5 RS-232 ports and at least 1 RS-485 upstream port will be needed. A total of six VME modules will be needed to support the IE Power and BiRa power supplies.

2 Low-Level RF

A new "network attached" LLRF controller has been developed for use throughout the C-AD accelerator complex. At the time of this writing, it is being commissioned for use in RHIC. In the next

few months it will be commissioned for use at the new EBIS, followed by ERL and eventually for the AGS and Booster.

The heart of the controller is a Xilinx Virtex-5 FPGA with an embedded PowerPC 440 processor, supported by 6 XMC "daughter card" sites providing ADC, DAC, and other functionality. LLRF algorithms and clock and pulse train synthesizers are implemented in the FPGA. Controls software executes on the PowerPC processor, providing configuration parameters to the LLRF clocks and algorithms, and monitoring system performance.

A cavity tuning feedback system, using both coarse (stepper motor-based) and fine (piezo-based) is being developed during early cavity tests. This system will be transitioned from the current (mostly analog) LLRF system to the new LLRF controller when the latter becomes available.

3 High-Level RF (Cavity & Gun)

Cavity incident, reflected, and transmitted power are measured via a commercial 4-channel desktop RF power meter (Boonton) using a GPIB interface, or via a 100 Khz, 16-bit VMEbus digitizer (after appropriate signal conditioning). Ultimately, a peak-power meter from the same manufacturer will partially or fully replace the RF power meter, thus providing measurements of the rapid changes in power that are observed while the ERL is in a pulsed mode of operation. This unit can optionally interface with the controls system via GPIB or Ethernet.

RF frequency readings are acquired from a meter transmitting measurement data at 1 Hz via an RS-232 connection to VME-based software. Two ports on a Digi Terminal Server module provide the connection to the controls system network for the Cavity and Gun RF systems.

High Power RF:
AB PLC5 will control/monitor the high power RF. A PLC 5/40B will interface the 1 MW power supply system to the ERL controls system. The 1MW system will not be used for the CET. If the interface is changed to an AB ControlLogix module, it could be integrated with the controls system via the Ethernet network.

50 KW RF:
This device has an internal controls system of some kind. It is unknown if it will be interfaced to the ERL controls system. No interface is defined yet.

4 Laser / Photocathode

This subsystem consists of the laser, associated timing and gating signals, pulse shaping and measurement stages, and (approximately 9 meter) transport to the photocathode. It does not include the access control systems and associated laser shutoff systems (Pockels cells and shutters). A block diagram is shown below.
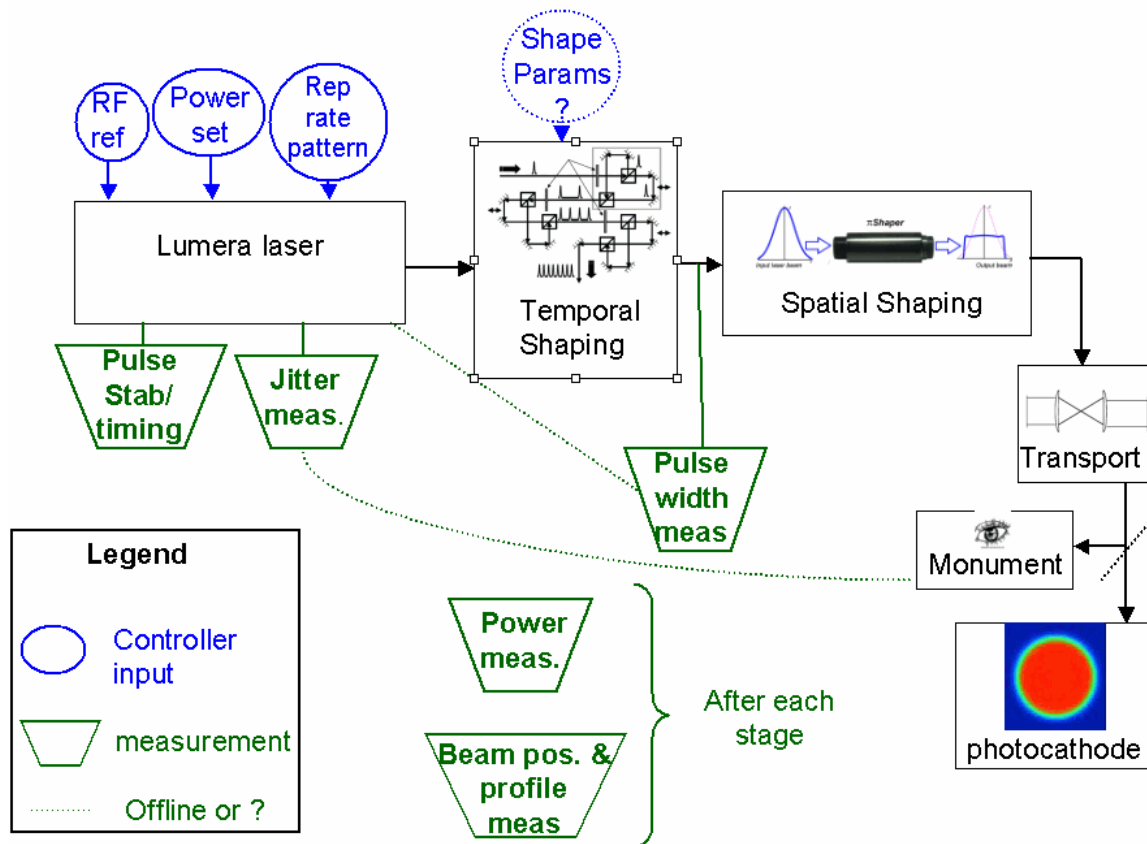
The laser is provided by a commercial vendor (Lumera). Laser timing and rep. rate signals will be derived from the master RF system clock. The RF clock system will provide pulse patterns to support diagnostic modes and intensity "ramp up" - to gradually increase the pulse train width over time to avoid excessive "droop" in the energy recovery cavity.

The laser includes a PC-based local user interface. Basic laser control (on/off) and monitoring (power measurements at various stages) is available through this interface. Remote control/monitoring can be performed using Windows Remote Desktop software. In addition, these functions will be made available through the control system, e.g. in order to support online archiving of the power measurements, alarm during off-normal circumstances, and allow sequenced facility startup and checkout. Lumera provides a Windows DLL interface that will be used to integrate the laser controls into the control system. Control software (either developed in LabView or C++) will run on the Lumera PC. This software will interface to the control system through the network.

A new injection ramp "chopper" VME module will be designed to support the three modes of operation and to provide a ramp-up of beam intensity. The new beam intensity ramp module will provide a gate to control the number of bunches injected and to smoothly increase the number of bunches in the ring.

Pulse width measurement will use an autocorrelation or similar technique. This requires control of an adjustable laser path length (precise linear motion of mirrors) and a high-speed measurement of the resulting cross-product signal. For stand-alone pulse width measurements, a LabView program supporting this functionality has been obtained from Menlo systems (as well as the National Instruments PCI-based 24-bit ADC card it depends on). For online (via the control system) autocorrelation measurements, the LabView program will be interfaced to the control system, or replaced with equivalent C++ software running on a LINUX server. For various other ad-hoc laser

beam diagnostics, the control system will provide an interface to a (Ethernet-based) digital oscilloscope and a desktop (USB) laser power meter, both interfaced via a LINUX server.

Temporal and spatial shaping stages consist of various optical elements which share the optical table with the laser. These are typically adjusted manually by laser experts and do not require remote control. However, for diagnostic purposes, laser power, profile, and position will be monitored after each of these stages, as well as after the transport to the photocathode. Laser power will be measured via UV-enhanced Silicon photodiodes, and digitized via a VME ADC module after appropriate gating and signal conditioning. Laser profile and position will be measured using a combination of high precision CCD or lower precision CMOS cameras. A total of 7 cameras will be interfaced to the control system using IEEE1394b "fire wire" high-speed serial interface, or possibly via a dedicated Gigabit Ethernet link. In either case, image capture and processing will be performed on a LINUX-based server., and logged at a rate of once per minute.

The beam transport makes use of 6 movable mirrors. Up to 4 additional movable mirrors may be needed at the photocathode end of the transport for final positioning. All will be controlled via Newport multi-axis motor controllers, interfaced to the control system via terminal servers to a LINUX server. Position feedback, e.g. to compensate for temperature-related drift, is feasible but not expected to be necessary at this time.
A polarizing filter, also controlled via a Newport motor controller, will be used to control final laser beam intensity on the photocathode. Remote controlled "flippers" may be used to intercept the beam at one of a few locations during normal operation (as opposed to access-controls beam shutoff devices). These will be controlled via a VME digital output module.

Pulse stability and timing (between the laser output and photocathode) will be measured using fast photodiodes at each point. These signals will also be digitized via the VME ADC module after appropriate gating (using rep. rate signals) and signal conditioning.

5 Electron Beam Instrumentation and Beam Component Controls
All data from electron beam instrumentation will be saved within a circular buffer to allow for time-constrained analysis of fast signals. Data will also be logged at 10 Hz for analysis of slower trends. Triggers will be provided either directly from the LLRF system, or through pico-second resolution DG535 delay modules.

Position Monitoring
Beam Position Monitor signal processing electronics of one of three possible designs will interface with the controls system via the Ethernet network. A commercial BPM module from Libera serves as the off-the-shelf option, while NSLSII personnel continue to develop a custom BPM module. A third proposed design would incorporate a Xilinx platform with ADC daughtercards, similar to the one described in the LLRF section that is already in use for the RHIC project. The Libera module includes Gigabit Ethernet support.

Loss Detection
Three different types of Loss Monitors will detect steering, optics, and beamline component issues at the ERL: Photo-Multiplier Tubes, Pin Diodes, and Heliax cable-based Ionization Chambers.

In the current controls system implementation for the Heliax Ion Chambers and PMT's, digital nano or pico ammeters are used to sample data from each signal source. Both types of devices are integrated

into the Ethernet network using GPIB connections to GPIB/ENET-100 Controller modules. LINUX-based server software provides the end-user interface. Two other designs are being considered for PMT data acquisition with the full ERL: VME modules of the same type as were developed for the RHIC, and a new Xilinx platform with ADC daughtercards. Each must be capable of generating a TTL interlock signal for use with the Machine Protection System.

Pin Diode information corresponding to beam losses are sampled by a VME DAQ scaler module.

Current Measurements
Two Bergoz DC Current Transformers will provide differential information between the injection and dump transfer lines. All data will be sampled by a VME 16-bit ADC module. It will be necessary for this system to output a TTL interlock signal for the Machine Protection System.

The per-bunch current signal from a Bergoz Integrating Current Tranformer will be digitized by a standard 16-bit VME ADC module capable of 100 kHz sampling. External triggers will synchronize data acquisition, and subtraction of baseline data will be performed in software.

Profile
Seven plunging-type Profile Monitors from Radiabeam will be installed. In addition to a pass-through mode, each device includes a screen optimized for beam profile image sampling at high energies and another for low energies. A CCD camera interfaced with existing controls infrastructure using IEE1394b (Firewire) will serve as the data source. Standard image analysis tools are provided in software for sigma, centroid, and chi-squared fitting to the beam profile. Separate controls for a 3-motor lens system must be developed, that will be based upon existing LINUX server software utilizing RS-232 connections to each device. Approximately six control bits will be generated and six status readback bits will be acquired using VME digital input and output modules for the plunging mechanism and lens systems.

Emittance
CCD images of the electron gun beam output hitting a Pepper Pot will be sampled using the existing frame-grabbing infrastructure.

Halo Scraper
At two different Injector beamline locations, pairs of mechanical jaws will be used to eliminate the halo portion of the beam. Each plane will be moved with a separate stepper motor that will require the use of one VME control module and several VME digital output and input channels for enable control and limit switch status readbacks. Position readbacks from a LVDT will be sampled by a VME 16-bit ADC module, which would in total utilize approximately 12 channels.

Wire Scanner
In support of a Wire Scanner device, standard VME modules for motor control of the wire mechanism and 16-bit ADC at a maximum of 100 kHz sampling of the analog output will be required for both the wire current and position data.

IR Video
Two Infra-red cameras used to monitor beampipe heating will integrate with the existing frame-grabbing system using a IEEE1394b (Firewire) interface. The infrastructure required to support 10 Hz video acquisition has already been developed for the RHIC Luminescence Monitor, using a dedicated Gigabit Ethernet link.

Beam Dump Temperature
Thermocouple signals will be digitized from four sensors located at the beam dump using a PLC, which will be capable of driving interlock inputs for the Machine Protection System. Digitized readings will be acquired over an Ethernet connection to LINUX-based software running on the controls system.

Faraday Cups
Current measurements using a Faraday Cup will be digitized using a VME 16-bit ADC module at 100 kHz using an external trigger. One VME digital input and output channel will be required for readback and control of the cup insertion status fore each device.

Streak Camera
A Streak Camera from Hamamatsu is being considered for use at the ERL. Its requirements include an external trigger, outputs to the existing controls infrastructure for frame grabbing, and development of software integration between the manufacturer's Windows/PCI-GPIB-based interface with the LINUX-based controls system.

Laser-wire Scanner
Use of a CO_2 Laser beam profile monitor is under consideration. This measurement could be performed using of a PCI DAQ module, an IEEE1394b Firewire interface for a CCD camera, and a trigger module. LabView software would provide the local interface to the devices, which could then be integrated into the controls system using existing LINUX-based server software. A Windows-based alternative might be advantageous, though this would require the development of additional interface software in order to integrate the scanner into the controls system.

Synchrotron Light Cameras
CCD cameras will focus on mirrors strategically placed at optical ports at four locations around the main ERL Ring. Each will collect the synchrotron light profile, which will be passed over IEEE1394b Firewire connections to the existing frame-grabbing system running on an ERL server.

6 Safety System Instrumentation (Chipmunks)
Radiation levels detected by 9 Chipmunk-type detectors are sampled using one VME DAQ scaler module. Interlocks from the Particle Accelerator Safety System (PASS) for the ERL are handled separately through inputs into the Machine Protection System.

7 Cryogenics
Data for seven different Cryogenic system measurements will be acquired through an existing LINUX-based server program. Once every five seconds, the current values are transferred over Ethernet networks from the VAX mainframe that supports the Cryogenic controls system to the controls system for the ERL project. This will allow correlation between slow trends in Cryo readings with the activities performed and readings acquired using the ERL controls interface. Machine Protection System interlock inputs from the Cryo system are handled separately.

8 Vacuum
All of the ERL vacuum controls systems have been developed utilizing existing hardware and

adaptations of LINUX server based software that is already in use elsewhere in the Collider-Accelerator complex.

Remote vacuum valve interaction is achieved using an Allen-Bradley PLC that communicates over an Ethernet network with the controls system. The PLC also provides vacuum interlock signals for the Machine Protection System.

Data is read and commands are sent to 10 cold-cathode and thermocouple vacuum gauges and 12 ion pump controllers using separate RS-232 serial connections for each device.

Remote control of two Varian turbomolecular vacuum pumps will be handled by turbo controller modules interfacing with the control system using RS-232 serial connections. The relevant vacuum valves are controlled through the separate PLC interface that is used for all valve control.

A dedicated pair of 16 port Digi Terminal Server modules provide the required 24 RS-232 connections for all vacuum equipment.

9 Infrastructure
Currently, two server PC's running Red Hat LINUX are used to support ERL operations, with one being dedicated to laser-related activities.

End-user access to the ERL controls system will be handled by three Wyse thin-client terminals located in the Control Room. Each terminal has the capability of connecting via Ethernet to three different remote hosts that are running as No Machine servers, and can drive up to two separate video displays.

Three VME chassis running VxWorks on multiple processor platforms are used to support remote device integration with the controls system. Remote diagnostics are also available for each unit via RS-232 connections. Continuous time synchronization between all chassis and a networked time server is achieved using Extended Network Time Protocol (XNTP).

RS-232 and 485 serial connections are integrated with the controls system Ethernet network using several different types of Digi Terminal Server modules.

All GPIB inteface devices are integrated with the controls system Ethernet network using National Instruments GPIB/ENET-100 modules.

Commonly used application software within the Collider-Accelerator Complex for device interaction (PET), live-information plotting (GPM), logged-information plotting (LogView), and video image display/analysis (FlagProfileMonitor) will continue to serve has the primary controls system tools for the ERL project. Motif Editor and Display Manager (MEDM) will be used to create synoptic displays that will eventually provide the primary user interface to the ERL.

A 100 Megabit Ethernet network serves as the backbone of the controls system. Dedicated Gigabit Ethernet links will likely be needed in support of selected high-frame rate video connections between video servers and the ERL Control Room.

Data logging services are provided by a set of networked servers shared by other projects at the Collider-Accelerator Complex. Each machine utilizes RAID storage in order to maintain a high level

of reliability.

10 Machine Protection System

The software user-interface for the Machine Protection System provides critical information on the status of input signals generated by each subsystem that has been deemed necessary to interlock the operation of the ERL. Changes in state of each input are accompanied by a latched timestamp, to aid in the process of diagnosing the root cause of each system interlock. The ability to enable or disable each input signal and reset any cleared interlocks is provided through the same interface.

In order to monitor the status of the MPS, a handshake signal is circulated between the LINUX-based server software, LabView-based software layers, and the National Instruments CRiO FPGA hardware that is monitoring all of the interlock inputs.

Additional input channels can easily be added to the software as new critical components are integrated with the ERL.