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CONTROLS SYSTEM DEVELOPMENTS FOR THE ERL FACILITY*

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Abstract

The BNL Energy Recovery LINAC (ERL) is a high beam current, superconducting RF electron accelerator that is being commissioned to serve as a research and development prototype for a RHIC facility upgrade for electron-ion collision (eRHIC). Key components of the machine include a laser, photocathode, and 5-cell superconducting RF cavity operating at a frequency of 703 MHz. Starting with a foundation based on existing ADO software running on Linux servers and on the VME/VxWorks platforms developed for RHIC, we are developing a controls system that incorporates a wide range of hardware I/O interfaces that are needed for machine R&D. Details of the system layout, specifications, and user interfaces are provided.

INTRODUCTION

Since the BNL ERL was conceived as an R&D testbed for a future electron-Relativistic Heavy Ion Collider (eRHIC) upgrade, many elements of the necessary Controls System have been designed and implemented. A 20 MeV superconducting 5-cell 703 MHz RF cavity that will accelerate and decelerate the electron beam passed its first milestone of the Cold Emission Test (CET) within the last two years [1]. Aside from further 5-cell RF measurements, Fundamental Power Coupler standing-wave RF conditioning was completed this summer for the superconducting gun FPCs at a power up to 125 kW (CW) and 250 kW (pulsed).

In 2012, the first ERL Gun-to-5-cell-cavity (G5) test where $\sim 1 \mu\text{A}$ electron beam will be generated using the gun/laser assembly and accelerated in a simplified, linear version of the ERL layout is expected to begin. The ultimate goal for the completed facility will be to verify efficient energy recovery while running CW reaching electron beam average currents on the order of ~ 0.5 Amperes [2].

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INFRASTRUCTURE

The ERL has benefited from a long legacy of hardware and software development at the Collider-Accelerator Department (C-AD). Where possible, we have leveraged existing interfaces that utilize our C++ Accelerator Device Object (ADO) based software running on both VME/VxWorks and LINUX Red Hat machines. Services such as archiving, logging, and storage are shared between ERL and the other parts of the C-AD complex, though they reside on a separate Ethernet subnet as shown in fig. 1.

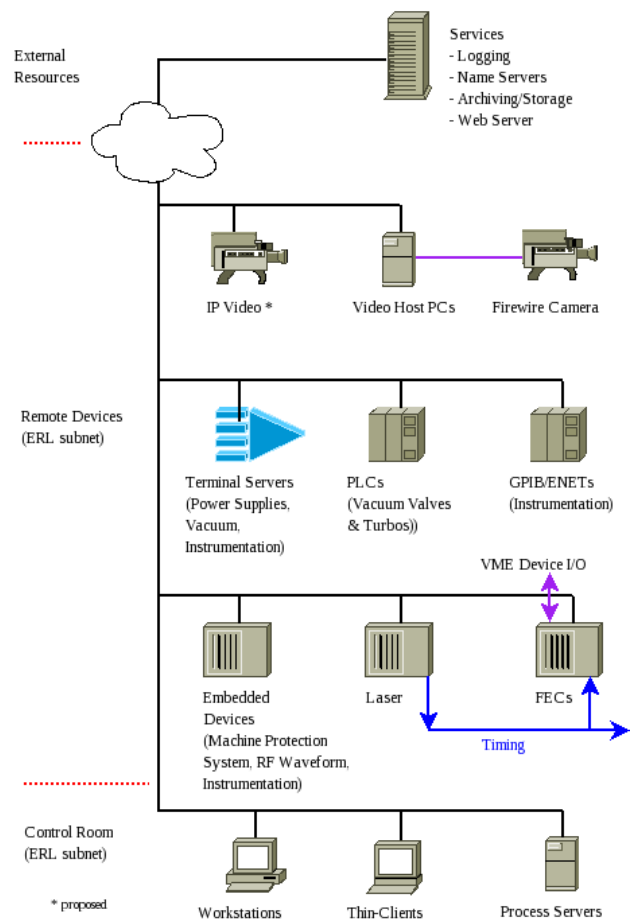


Figure 1: ERL Controls network-based architecture, including existing and proposed elements.

For legacy reasons, the Cryogenic System resides on an independent controls system and subnet of the Ethernet network. For the purposes of ERL, selected Cryogenic

data is transferred to the Controls System at a rate of 0.2 Hz. Details of the Machine Protection System (MPS) can be found in ref. [3].

INSTRUMENTATION

Beam Position Monitors

ERL beam position monitor signals will be processed using Libera Brilliance Single Pass modules from Instrumentation Technologies. Five of these devices will be used during the first ERL beam tests scheduled for early 2012.

The Libera device includes an ARM processor, on which an embedded configuration of LINUX runs, providing access to the functionality of the device via a vendor-supplied library and collection of kernel modules. The vendor also provides a cross-development environment, to allow software development on a conventional desktop LINUX system.

Using the cross-development environment and the library's programming interface, software was developed which runs on the Libera's processor, providing remote access to the device's functionality. The code base is identical to the code base used for VME or other embedded systems used in the facility. In this manner, each Libera device appears, from the control system perspective, to be just another network-attached embedded controller.

Each device will provide a TTL signal that will be used by the MPS to interlock when position readings stray from acceptable values.

Beam Loss Monitors

Four types of electron beam loss monitoring detectors are employed at the ERL: Photo-Multiplier Tubes (PMTs), Ion Chambers (IC), Helix cables, and PIN Diodes.

The PMTs & ICs will provide current signals with respect to loss levels that will be processed by custom VME based amplifier/integrator/detector cards currently used in the RHIC beam loss system. These cards provide analog signals to standard VME ADC modules for monitoring and a TTL output for beam loss interlock level to the MPS. CAEN 24 channel HV VME controller modules will supply individually controllable references for the PMT high-voltage bias allowing each of the 14 PMTs to be "tuned" for a desired response. The 8 ICs are biased collectively by a manually adjusted supply.

The 16 Helix cable detectors each have their own pair of bias supply and integrator module, identical to what is currently used for beam loss detection in the Alternating Gradient Synchrotron (AGS). Analog output loss data will be digitized using VME ADC modules, and control will be effected using a VME digital output module.

Eight Bergoz BLM PIN diode modules have been employed at the ERL using a SIS VME scaler module for data acquisition and a VME digital output module for calibration pulse control.

One TTL signal will be provided to the MPS that will indicate the status of the beam losses relative to a trip threshold.

Beam Profile Monitors and Cameras

A series of actuated profile monitors from Radiabeam Technologies will be used to gather information regarding the electron beam profile from light gathered from both YAG and Optical Transition Radiation (OTR) screens. Standard VME digital I/O modules will provide the insertion controls for each multi-position instrumentation package, and image capture will be performed using a setup that includes a LINUX host PC with a IEEE1394 Firewire interface to the attached camera. The image gathering and analysis software has been well-documented in ref. [4] using our custom ADO toolset.

To date, LINUX software Firewire support issues have prevented the active use of more than one camera per host PC through our standard software. As a potential alternative, we will evaluate a Gigabit Ethernet camera for use at the ERL. The feasibility of using low-cost, "lightweight", dedicated host PCs instead of the more expensive multi-role servers that have been previously used will be explored as well.

Multi-axis lens controller modules from Image Labs will be used to adjust the picture for each camera. LINUX ADO software provides remote access to the device through a serial terminal server for up to two cameras per unit.

A TTL insertion status signal from each profile monitor will provide an input with which to interlock the MPS under high average beam current conditions in order to prevent damage to the YAG flag screens.

Pepper Pot

Electron beam emittance measurements will be acquired and presented via a remote interface that is currently being designed. One possible implementation of the system would make use of existing PC-based data

acquisition and would require further development of custom software that has been created to perform similar measurements for the Electron Beam Ion Source (EBIS) project. Actuator controls will make use of VME digital I/O modules.

Halo Scraper

Six scraper jaws will be used in the injection straight and zig-zag sections to remove the electron beam halo in support of measurements under limited average beam current conditions. Each jaw is actuated using stepper motor controllers interfaced with VME Front-End-Computers (FECs) that provide position control, position readings, and limit switch detection. The motion controller interface software was created for previous projects.

Signals derived from controller status relays are expected to provide the necessary MPS inputs in order to protect the scraper jaws from intercepting high average beam currents while running in a high intensity mode.

Faraday Cups

The halo scrapers will perform double-duty as Faraday Cup pick-ups. Three additional Faraday Cup beam dumps will be installed for the measurement of beam current during the initial G5 tests, progressing to six in the zig-zag portion of the G5 injection transport. VME analog modules will be used for the data acquisition to the Controls System through custom Faraday Cup amplifier cards installed in a Eurochassis. External triggering of the sampling will be performed using a VME delay module that was created for past projects.

Integrating Current Transformer

The Bergoz BCM-IHR ICT will monitor the performance of the accelerator and alert the MPS should the beam current exceed the maximum allowed for a given operational mode. Gain, calibration pulse parameters, and signal polarity control will be provided using VME digital output modules, and triggering of the integration will be executed using a VME trigger delay board.

Methods for transmitting the ICT statuses to the MPS are currently being reviewed.

Differential DC Current Transformer

A platform is in the planning stages that has the goal of providing beam current readings from matched Bergoz NPCT transformers in the injection and beam dump transport while comparing both signals with a reference

generated by a current source. A loss of current between the two transformers over a desired threshold would trigger an input to the MPS as an indication of significant beam losses. The merits of two basic options are under review: PLC-based sampling with interlock outputs, or a Xilinx processor paired with ADC and digital output daughter cards. The latter platform has been used for an increasing number of RF [5] and Instrumentation projects at C-AD in recent years, each using the VxWorks OS. Additional VME trigger delay module channels are needed to gate the data acquisition.

LASER

The electron bunch is initiated at the photocathode in the superconducting gun by a 9.38 MHz laser. The laser is a mode-locked Nd:YVO₄ master-oscillator power amplifier of custom design (Lumera Laser GmbH), required to achieve the low repetition rate and phase-locking requirements. The frequency-doubled output will be further conditioned by transverse and longitudinal shaping techniques [6]. Basic controls provided by the manufacturer are accessed using an attached PC running the Windows XP operating system. Efforts to implement a remote interface for the laser on the Controls system have previously involved the creation of a C++ server process in Cygwin that allows for direct integration with our infrastructure over Ethernet. Increasing concerns over Cyber Security issues and the hardware limitations of the included PC may result in a change in control strategy. The primary alternative would be to create a remote ADO server running on a LINUX machine that would interact with the laser PC over a serial connection.

Laser beam transport steering and shaping is achieved using a series of Newport gimbal mirror assemblies that can be moved by piezo actuators interfaced with a Newport 8-axis motor controller module. LINUX software has been developed to remotely send commands and return readings from each device.

An autocorrelation measurement system is under development, which will utilize an externally triggered fast ADC VME module in order to sample light from a photodiode synchronously with the laser pulses. Software has been developed to control another Newport linear actuator, which will be adapted to gather the digitized beam signal in conjunction with the motion of the photodiode.

Since the laser clock will provide the master timing for other systems at the ERL, a method for synthesizing related timing signals is needed. To that end, a Stanford

Research Systems DG645 Digital Delay Generator will be used. LINUX software has been created to provide remote I/O over Ethernet for the device.

RF

Low-Level RF control of the 5-cell cavity tuner was first achieved using an analog phase-locked loop (PLL). This included motion controller and ADC VME boards for the cavity tuning feedback control, and a digital I/O VME board for gain control. Such a system was used successfully in support of the CET, and for further cavity tests since then. This included microphonics measurements [1] gathered from a fast ADC VME module that samples the LLRF signals in addition to the RF incident, reflected, and transmitted power. Over the course of multiple cold tests of the cavity, it became apparent that we were experiencing frequent gaps in data gathering from the digitizer when the total number of clients using the data exceeded a relatively small number. This issue was eventually resolved by first lowering the sampling rate from 16384 Hz to 4096 Hz, and then by configuring a data reflection server that shifts the client load from the FEC to the server's host machine. Details of a digital replacement for the analog LLRF platform can be found in ref [5, 7].

Additional CW RF power measurements are performed by two meters from Boonton. Data is relayed to the Controls System over a GPIB interface and GPIB to Ethernet bridge to a LINUX server process. Since there is also a need for pulsed RF power measurements, there is a separate LINUX program that acquires pulsed measurements from another Boonton meter over Ethernet.

POWER SUPPLIES

ERL main and trim dipole, quad, and solenoid magnets will be operated using power supplies from four different manufacturers: IE Power, BiRa, Kepco, and Danfysik. The controls for the former two types will leverage existing hardware and software interfaces, including the BNL Power Supply Controller (PSC) and commercial analog I/O VME modules. The Kepco and Danfysik units make use of serial I/O, though they will be configured for RS232 and RS485 respectively. User interfaces are provided through separate LINUX processes that utilize the Ethernet network and a serial Terminal Server.

Software development has been completed for the Kepco power supplies, and efforts to configure the intermediate hardware for the Danfysik interface are underway.

USER INTERFACE

The foundation for ERL user interfaces is firmly rooted in the existing application paradigm at the BNL C-AD: basic device interaction is performed through the Parameter Editing Tool (PET), live data graphing is available through the General Purpose Monitor (GPM) application, and logged data can be plotted through the LogView application.

Being that the ERL is a much smaller facility than others at the C-AD, we chose not to implement an alarm system. Instead, facility users have expressed a desire for synoptic displays that would graphically highlight any abnormal conditions, and allow the user to quickly drill down to the necessary subsystem controls in order to address the cause. Limited testing has been performed using MEDM on LINUX. We are currently planning on creating control pages using MEDM for the G5 tests, though evaluations of alternative graphical process control systems will likely continue in parallel.

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