**TITLE: RAPID DEVELOPMENT OF A MEASUREMENT AND CONTROL
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RAPID DEVELOPMENT OF A MEASUREMENT AND CONTROL SYSTEM FOR THE ADVANCED FREE-ELECTRON LASER*

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ABSTRACT

The Experimental Physics and Industrial Control System (EPICS) is being used to develop a measurement and control system for the Advanced Free-Electron laser (AFEL) at the Los Alamos National Laboratory. EPICS is an integrated system of applications development tools and a distributed run time environment that supports an input-output database, a graphical operator interface, sequential control through "state" definition, data archiving, data analysis, and fault management. It is very advantageous in terms of both time and system integrity to be able to perform much of the control system development before the actual hardware for the AFEL is in place. Using the EPICS applications tools, we are developing prototype measurements and controls that can be directly transferred to the AFEL during installation and commissioning. This is possible due primarily to three aspects of EPICS. First, we can easily model physical systems with the state notation language. Second, we can simulate input and output channels with "soft" database channels, which are created using the database configuration tool. Third, we can easily build and modify operator interface screens with the display editor.

1. Introduction

The Advanced Free-Electron Laser (AFEL) project has been designed to demonstrate convenient and user-friendly instrumentation and control in its operation from the outset. It must also demonstrate highly reliable start up and operation. Hence, the control and instrumentation system should be easy to configure, convenient to use, include a high degree of error checking, and provide an operator interface that is easy to understand.

To minimize both cost and effort in the development of such a system, we chose to use EPICS (Experimental Physics and Industrial Control System) as the control and instrumentation system for the AFEL. Given the inherent ruggedness of the hardware and

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the flexibility to design and configure the system to our needs, we felt that this approach would lead most rapidly to a satisfactory solution.

Through the use of simulations and mockups, we have been able to prototype many parts of the control system long before the actual hardware associated with the AFEL was available to us. This prototyping should significantly reduce setup time, once the actual experiment is in place.

EPICS¹ is a mature platform for implementing automatic control, supervisory control, and data acquisition. It was originally developed for the Ground Test Accelerator (GTA) at the Los Alamos National Laboratory with support from the Ground-Based FEL program. Engineers at the Advanced Photon Source at Argonne National Laboratory are working with Los Alamos to provide further enhancements to the software.

2. AFEL Measurement and Control Requirements

The philosophy governing the choice of a measurement and control system for the AFEL is that of incremental development. Because the performance of any large system is in many ways unknown until the system is in place and running, it is difficult to design a complete automatic control system at the outset. Initially, the operator will perform all control operations, and the software will check only for limits and the proper sequence of operations. An understanding of the system will be achieved only if data are acquired during this period of operation. As more of the AFEL characteristics are understood, these control operations will be automated.

A variety of functions will need to be performed by the measurement and control system. For example, the radio frequency (RF) system for the linear accelerator, including the klystron, the master oscillator, and the gating pulse generator, must be monitored and adjusted. Further, the various elements of the beam optics, including dipoles, quadrupoles, and steering magnets, must be adjusted and optimized for best electron beam quality in the wiggler. A variety of pulse information from RF pickup loops and beam position monitors must be measured and presented to the operator in a meaningful way. Finally, various optical components, such as injection laser steering mirrors and FEL cavity length, must be monitored and adjusted. Ultimately, all these operations will be automated.

3. The EPICS Control System

The EPICS provides distributed processing within a high performance run time environment, and includes a comprehensive set of applications development tools. The architecture, shown in Fig. 1, uses various classes of specialized nodes on a local area network (LAN). Input-output controller (IOC) nodes provide the primary data acquisition and

control functions. IOC nodes are based on the VME and VXI standards and use 68020/30/40 processors. A multitasking, diskless real time operating system runs on each IOC node. UNIX workstations provide a platform for developing applications and also serve as operator interface (OPI) consoles. All nodes communicate over a 10 MB/s fiber optic ethernet.

The distributed architecture allows for fast input-output (I/O) through VME modules and local, intelligent processing. I/O subnets², such as Allen-Bradley remote I/O, GPIB, and BitBus, offer lower cost alternatives for large numbers of channels that have lower performance requirements.

Fig. 1. Major elements of the EPICS architecture.

The EPICS run time environment, shown in Fig. 2, supports all major control and data acquisition functions: I/O, operator interface, alarm detection and notification, data archiving, and automatic control. The IOC nodes contain a distributed, run-time database³, which serves as an interface to all control and data acquisition hardware. In addition to controlling I/O, the database provides many low-level control functions, and is used to communicate between higher level control, data acquisition, and operator interface processes. Soft channels (channels that are not associated with input or output devices) are used to communicate between various processes in the system and to take the place of input or output devices during system prototyping.

The channel access protocol⁴ acts as a software bus for connecting these processes to the database. Channel access provides network-wide, run time resolution of the location and attributes of channels. Asynchronous operation allows event-driven programming.

The operator interface (OPI) emulates control panel operations through a high resolution, interactive color display. A mouse or trackball provides selection and control of displayed objects. A workstation typically displays multiple OPI screens in overlapping and adjacent windows.

The alarm manager⁵ displays in a window on the OPI console. It presents a hierarchical view of system-wide or subsystem alarm conditions. Alarms may occur and be acknowledged anywhere in the hierarchy, resulting in their quick detection and resolution.

The data archiver acquires and stores data from specified database channels. This acquisition may be initiated and terminated from the OPI, from a program, periodically, or by conditions of specified database channels.

Applications may be executed as either user-defined tasks (programmed in C) or under the sequencer. The sequencer implements event-driven, sequential type operations, such as vacuum system control and accelerator start up.⁶

Fig. 2. The EPICS run time environment.

EPICS uses the “toolkit” approach to building control applications.^{7,8} Each EPICS run time module is supported by a corresponding applications builder as shown in Table I.

Table I. EPICS Run Time Modules with Corresponding Applications Builders.

Run Time Module	Corresponding Applications Builder
Database	Database Configuration Tool (DCT) defines I/O channels, soft channels, and custom low-level control
Operator Interface	Graphic display editor builds display screens and assigns database channels to display and control elements; based on X-windows
Alarm Manager	Alarm Configuration Tool defines hierarchical alarm groups and alarm conditions
Archiver	Archiver User Interface (AUI) defines database channels to be archived and conditions for archiving; also provides graphic access to archived data
Sequencer	State Notation Language (SNL) converts a state transition diagram description into efficient run time tasks; does not require extensive real-time programming

4. Implementation of Prototype AFEL Controls

EPICS is being used to develop prototype controls and instrumentation for the AFEL. The development environment for AFEL controls is shown in Fig. 3. In addition to operator consoles (also used for building the applications) and a single IOC, there are a number of I/O devices that are representative of those that will be used on the AFEL. The final system will contain several IOCs and many more devices, but the development system is versatile and powerful enough to handle most prototyping.

Although the AFEL hardware is not expected to be implemented for several months, much of the control system is being developed and tested in advance of the actual commissioning of the AFEL. Simulations of some of the expected AFEL dynamics were achieved with the sequencer and soft database channels. Furthermore, various hardware simulators, such as voltage sources and a dummy vacuum system, mimic inputs from the AFEL. The prototype measurement and control system uses a repertoire of operator interface screens to control various aspects of operation of the AFEL. In addition to the main control screen, which gives an overview of the entire AFEL system, there are specific screens to deal with the vacuum system, RF controls, the linear accelerator, the beamline, and the photoelectric injector drive laser.

One of the unique aspects of the AFEL is its exclusive use of permanent magnet beam optic components throughout the beam line. Stepper motors are used to adjust the setting on these elements through the control system. A specialized operator display screen provides setup and fine tuning of the beam propagation parameters.

Finally, a number of state notation language programs are used to monitor and control the the setup and operation of the AFEL. To prevent the operator from performing potentially harmful operations, a series of built-in checks has been incorporated into the system.

Fig. 3. AFEL development configuration.

5. Summary

A small team of control engineers and programmers rapidly developed prototype controls for the AFEL using EPICS. The tools to build the run time database, operator displays, and sequence programs proved valuable in this application and saved considerable time and effort. For example, the ability to simulate I/O signals with soft database channels permitted early development of algorithms and displays.

6. Acknowledgments

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