A DEVELOPMENT AND INTEGRATION ANALYSIS OF COMMERCIAL AND IN-HOUSE CONTROL SUBSYSTEMS

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Abstract

The acquisition and integration of commercial automation and control subsystems in physics research is becoming more common. It is presumed these systems present lower risk and less cost. This paper studies four subsystems used in the Accelerator Production of Tritium (APT) Low Energy Demonstration Accelerator (LEDA) at the Los Alamos National Laboratory (LANL). The radio frequency quadrupole (RFQ) resonance-control cooling subsystem (RCCS), the high-power RF subystem and the RFQ vacuum subsystem were outsourced; the low-level RF (LLRF) subsystem was developed in-house. Based on our experience a careful evaluation of the costs and risks in acquisition, implementation, integration, and maintenance associated with these approaches is given.

1 INTRODUCTION

There were several reasons the control systems for major subsystems were outsourced for the LEDA project. A major reason was that delivery of the subsystem control system along with the subsystem allowed complete testing at the supplier's location before shipment. From our experience with several subsystems, we will analyze aspects of these implementations and provide strategies for successful acquisition of future subsystems.

2 SUBSYSTEM OVERVIEWS

Provided below is a summary of each subsystem included in this study. Brief descriptions of the computer system hardware, software, and external interfaces are presented. These subsystems have been, or are being, integrated into the integrated control system for LEDA, which is based on the Experimental and Physics Industrial Control System (EPICS). [1]

2.1 RFQ Resonance-Control Cooling Subsystem

The RCCS is a water cooling system used to maintain the RFQ's temperature, thereby controlling the resonant frequency of the accelerating cavity. Provided by Allied Signal, the RCCS includes an EPICS input/output controller (IOC) connected to devices like flow meters, thermocouples, valves, variable-speed pumps, etc.

2.2 High-Power RF Subsystem

The high-power RF subsystem control system is comprised of two PLCs used to control each klystron. An Allen-Bradley PLC-5/40 interfaces to the klystron control electronics (called the "transmitter"), and an Allen-Bradley SLC 5/03 interfaces to the high-voltage dc power supply. The transmitter provides magnet power, ac filament power, and crowbar triggering for the klystron, and the power supply provides the cathode voltage for the 1.2 MW continuous wave klystron amplifiers. Both PLCs were provided and programmed by the vendors as part of the purchase specifications for the equipment – Continental Electronics Corp. supplied the transmitter, and Maxwell Technologies supplied the power supply.

2.3 RFQ Vacuum Subsystem

The RFQ vacuum subsystem is used to achieve high vacuum. This subsystem was contracted to Lawrence Livermore National Laboratory (LLNL), and consists of five cryo pumps, two scroll pumps, and one turbo pump. Control is implemented using a Modicon PLC for equipment interlocks, Granville Philips ion-gauge controllers, and a Labview system for operator display and automatic shutdown.

2.4 LLRF Subsystem

The low-level RF subsystem is comprised of 5 VXI boards used to control the cavity field and resonance and to provide high-power RF protection and RF reference frequency generation and distribution. The clock distribution module provides the master timing signals to the other modules. The field control module provides feedback/feedforward I/Q control based on beam and field I/Q inputs. The amplifier control module compensates for individual klystron phase differences to 10 kHz. The resonance control module controls cavity resonance and allows for frequency agility during cavity warm-up. The high-power RF module protects the klystrons, windows, loads, and the accelerator from excessive reflected power.

The VXI boards were developed and programmed by the LANL RF group, and the external interface is via the slot zero controller mounted in the VXI chassis.

3 EVALUATION OF COST AND RISKS

All four subsystems described above are, or will be, integrated into the LEDA instrumentation and control system. This integrated system is implemented in EPICS, a control system tailored for accelerator and research applications. Whether the subsystems were outsourced or developed in-house had a definitive impact on the cost and risks involved in acquisition, implementation, integration, and maintenance. Each of these areas is discussed below.

3.1 Acquisition

The acquisition cost for outsourced subsystems is difficult to quantify, particularly when the control systems portion is not identified as a separate, billable expense. However, a general estimate on the materials and effort involved is possible.

In the case of the RCCS, it was developed using hardware specified by the LANL Accelerator Controls and Automation group, which has primary responsibility for the integrated LEDA control system. When compared to a typical EPICS system design as developed by the Controls group, the only extra component added by the supplier is the learning curve required to become productive with the EPICS toolkit. This has been estimated at 3 man-months effort for this supplier.

In the case of the high-power RF subsystem, the materials include the two PLCs and their associated input/output modules, sensors, and cabling. Approximate costs of these are on the order of $25K. The effort includes the PLC programming, installation and testing by the vendor's control system engineer, as well any support provided by LEDA personnel involved in factory and site acceptance testing. This has been estimated at 12 man-months for the system.

In the case of the RFQ vacuum subsystem, it was developed using Labview due to LLNL's familiarity with that software, and the steep learning curve for EPICS. Interlocks were programmed into the PLC's ladder logic, and the automatic shutdown sequence was implemented in Labview. This Labview system is being replaced with an EPICS implementation for LEDA. The effort to support requirements definition and equipment testing has been estimated at 9 man-months.

In the case of the LLRF subsystem, the acquisition cost and risks are nonexistent. They are instead reflected in the implementation section.

3.2 Implementation

The RCCS took approximately 10 man-months to implement. Collecting requirements took 4 months, developing device drivers took 5 months, and testing took 1 month. Had the subsystem been implemented in-house by the LANL Controls group, it is estimated that 4 man-months could have been eliminated. However, this would have impacted the schedules of other subsystems due to resource limitations. Also, problems were encountered during device driver development and integration with the RCCS that required additional implementation time.

Since the high-power RF subsystem used two different models of PLCs, implementing the EPICS interface proved somewhat difficult. The PLC-5 communicates to other PLCs via Allen-Bradley's DataHighway Plus or DF1 protocols, while the SLC communicates via DH-485 or DF1. Since DF1 is the common protocol, an EPICS device driver was written to allow communication between a PC IOC and the PLCs. Coding and testing of this driver took approximately 4 man-months, and development of a fault logger similar to the vendor's implementation took approximately 2 man-months. There will be three klystrons connected to the LEDA RFQ. A commercial, off-the-shelf (COTS) hardware board was ordered for each klystron's PC IOC, at a cost of $750 each, to communicate with the transmitter PLC via DataHighway Plus. Communication with the power supply PLC is via the PC's serial port. Interfaces to the integrated control system were allowed for, but integration details were not initially designed. Had the LANL Controls group implemented the klystron controls, a large portion of the PLCs ladder logic would have instead been implemented in the EPICS IOC to reduce maintenance costs.

The RFQ vacuum subsystem was implemented in 4 man-months, which was spent developing the Labview display, automatic pumpdown sequence, and Modicon PLC program. Device drivers for the GPIB communications protocol were already supported in EPICS, but the Modicon PLC interface driver had to be created.

In the case of the LLRF subsystem, control system materials include only the slot zero controller and associated software licenses. Costs of these are on the order of $10K. The effort includes the software installation and configuration, ethernet wiring, and device driver development for each VXI module. This is estimated at about 11 man-months.

3.3 Integration

The RCCS was easily integrated into the LEDA control system, since it was designed as an EPICS application. Integration costs included implementing the database, sequences, and displays, and is estimated at 9 man-months.

For the high-power RF subsystem, EPICS database and operator screen development took 12 man-months for the first klystron. A considerable amount of time was spent analyzing the data available in the two PLCs and determining how best to duplicate this information for the other klystrons to be added to the network. Subsequent klystrons will be added rather easily due to the repetitive nature of the design, and this is estimated to take 0.5 man-months per additional klystron.

The RFQ vacuum subsystem was integrated into the LEDA control system by porting the Labview application to EPICS, and took 2 man-months. This includes reviewing the requirements, using the ladder logic and Labview programs as a foundation. Integrating a GPIB device took 2 days, and overall system testing by LLNL and LANL is expected to require another man-month.

Integrating the LLRF subsystem is ongoing. EPICS device drivers are being written for each VXI module as they are delivered, and engineering databases and screens are being developed for testing and commissioning purposes. This effort was included in the implementation section. Further integration with the high-power RF subsystem databases and screens will take another 3 man-months, after obtaining all operational requirements.

3.4 Maintenance

Maintenance costs for these subsystems are affected by formality of the vendor relationships and the familiarity the LANL Controls group has with the overall system design. For instance, maintenance of the RFQ vacuum subsystem is not expected to take any extra time, since the ladder logic is the only component remaining from the original system design, and familiarization with that software was required to implement the porting into EPICS. Also, the LANL Controls group will now have maintenance responsibility for that software. However, high-power RF subsystem maintenance is complicated by the fact that all ladder logic changes will remain the responsibility of the vendors. This is likely to result in longer response times for software revisions, which could impact LEDA operations since some control algorithms and sequences are implemented in the PLC and not in the EPICS IOCs. Maintenance concerns are minimized for the RCCS and the LLRF subsystem since these are strictly EPICS implementations, and are only limited by the resources available to the LANL Controls group to perform these tasks.

4 SUMMARY

The effort involved in implementing a control system with subsystems developed by both outside suppliers and in-house personnel is affected by many factors. Included in these are the overall complexity of the subsystem, the amount of software to be developed while integrating new modules, and the amount of communication between subsystem developers and the integrated controls group. Table 1 lists efforts in man-months for the acquisition, implementation, and integration of the four subsystems discussed above.

Phase	RCCS	HPRF	RFQ Vacuum	LLRF
Acquisition	3	12	9	0
Implementation	10	6	4	11
Integration	9	13	3	3

Table 1. Effort (man-months) for Each Subsystem

5 CONCLUSIONS AND RECOMMENDATIONS

Although the LEDA control system is not yet fully operational, the following conclusions can be drawn from the experience gained to date in this effort:

- The amount of involvement in subsystem design and implementation by the LANL Controls group is inversely proportional to the effort to integrate each subsystem in the LEDA control system.
- Surprisingly the largest amount of time spent developing and integrating these subsystems into the LEDA control system has been in collecting requirements.
- When there are repeating elements in the control system, as is the case with the klystron PLCs, time spent replicating added elements is greatly reduced by carefully evaluating and planning the initial design.

The following recommendations can be made to improve future developments, both in outsourcing and in developing in-house:

- Ensure the personnel responsible for the integrated control system are involved in establishing subsystem requirements.
- Ensure the personnel responsible for the integrated control system are involved in periodic reviews of subsystem implementation.
- Reduce the role of PLCs in the design to that of equipment protection interlocking, and implement all sequencing and control algorithms in the EPICS IOCs. This will reduce complexity of the PLC design, and improve the flexibility of the integrated control system.
- When outsourcing, include in the purchase requisitions a minimum response time to software and hardware change requests, and add a minimum time period where there are no fees for these changes.
- When developing custom hardware in-house, the schedule must include time to integrate and test these components into the overall control system.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] M. E. Thuot et.al., "The Success and The Future of EPICS," Proceedings of XVIII International Linac Conference, Geneva, Switzerland, August 26-30, 1996.