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INTEGRATION CHALLENGES AND SOLUTIONS FOR LOW LEVEL CONTROLS SYSTEMS AT THE FRIB*

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Abstract

The FRIB, is a new heavy ion accelerator facility currently under construction at Michigan State University. It is being built to provide intense beams of rare isotopes. The low level controls system integrates a wide variety of hardware into an EPICS/PLC based control system. This paper will present the challenges encountered with resulting hardware interfaces, and lessons learned that can be applied to future projects. These challenges include both technical design and project management challenges that are encountered when integrating hardware from other departments.

INTRODUCTION

FRIB is designed to accelerate all the stable isotopes from hydrogen through uranium to energies greater than 200 MeV/u with beam power up to 400 kW. It is comprised of two ion sources, an RFQ, 46 superconducting RF (SRF) cryomodules comprising the accelerator portion of the machine, a cryoplant, a target facility utilizing superconducting magnets, and will connect into the existing National Superconducting Cyclotron experimental beamlines, (see Fig. 1). This new higher power accelerator has presented a number of new control challenges over the existing cyclotron systems and experiences; a few of those are documented here.

CONTROL PROCESS IMPROVEMENTS

The FRIB Cryoplant Control System

The FRIB cryoplant presents special challenges and constraints on the control system due to its nature as a continuous process plant providing a vital utility to the accelerator. The cryoplant control system must be designed to have the maximum possible uptime due to the fact that the helium inventory must be maintained even when the accelerator is off. The cryoplant controls are largely analog in nature and are comprised of a complex series of feedback loops for temperature and pressure regulations, as well as control of rotating machines such as screw compressors and turbo expanders.

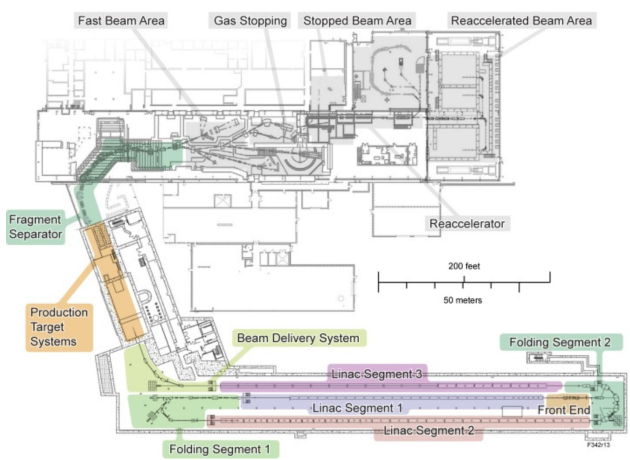

Figure 1: Schematic layout of the FRIB (colored areas) and existing infrastructure (gray).

The Cryoplant is controlled entirely by Allen Bradley ControlLogix PLCs utilizing the enhanced PID (PIDE) version of the ControlLogix PID instruction. This system utilizes the velocity form of the PID control equation with independent gains and many tuneable parameters.

The control algorithm of the PIDE instruction operates on percent error rather than absolute error providing a couple of benefits. Process values may be chosen with a wide variety of ranges during runtime. Gains are always applied against a known scaling (0 to 100% input) so the

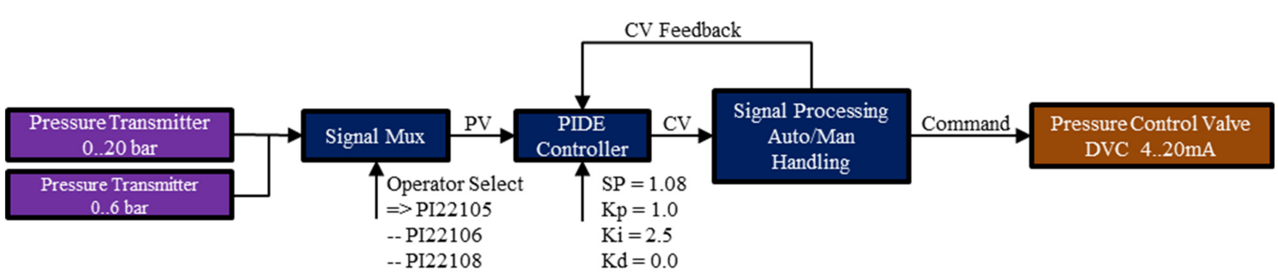

Figure 2: Example PIDE implementation for FRIB cryoplant.

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same gains can be used in multiple locations with different process conditions and provide predictable output behavior, as exemplified in Fig. 2.

Several in-house control blocks have been developed which work with the built-in PIDE to allow real-time switching of process variables, bumpless transfers between operating modes, split-range rate limiting, integrated override and interlock support. The use of standardized control blocks allows for the development of templated faceplates and control panels for the operator reducing errors and overall implementation effort. It also provides flexibility for more complex situations.

SRF Cavity Automated High-pressure Rinse (HPR) System

The original SRF high-pressure rinse system used at the FRIB consisted of a rotary table and a rinse wand on a linear actuator [1]. The HPR system had a high cost of labor due to dedicated operators and required multiple fixtures to support and align the cavities, as shown in Fig. 3.

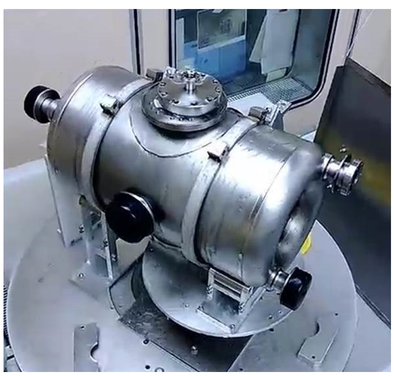

Figure 3: Original HPR fixture.

The original system also had the potential for cavity damage and contamination. After evaluating new designs, a fully automated commercial six-axis cleanroom certified robotic arm and a rotary seven-axis cavity support fixture was selected, and is now used to perform high-pressure water rinse on the FRIB cavities (see Fig. 4).

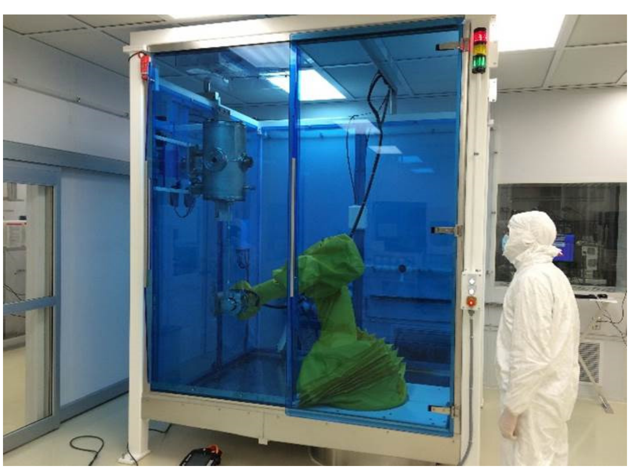

Figure 4: Robotic HPR system installed at FRIB.

The new automated system removed the requirement for changing multiple fixtures and operator manipulation of the cavities both of which can introduce cavity damage or contamination. The system also removed the need for dedicated operators resulting in an estimated 2500 hour reduction in labor for cavity processing over the course of the project. The commercial robot is easily reprogrammable, and can accommodate changes in the rinse cycle, as well as be adapted for new model cavities in the future. This was also a lower cost option compared to the other design alternatives.

Superconducting Cryomodule Instrumentation

The superconducting cryomodules used in the FRIB had a high number of raw signals to interface with providing temperature, pressure, helium levels, superconducting magnet lead drops voltages, and so forth. Where possible and economical, commercial monitors were used to provide readbacks to the control system. Another more flexible option was the use of 5B isolated signal conditioners which generate an analog output voltage compatible with PLC analog inputs. The 5B modules can interface to a variety of instrumentation such as temperature sensors, strain gauges, lead drop voltages, coil voltages, and potentiometers as some examples.

A custom 19” chassis and 16 channel connector printed circuit boards (PCBs) were designed to produce a compact 4 rack unit package. This chassis would hold up to three connector boards, allowing for up to 48 channels of instrumentation per box (see Fig. 5).

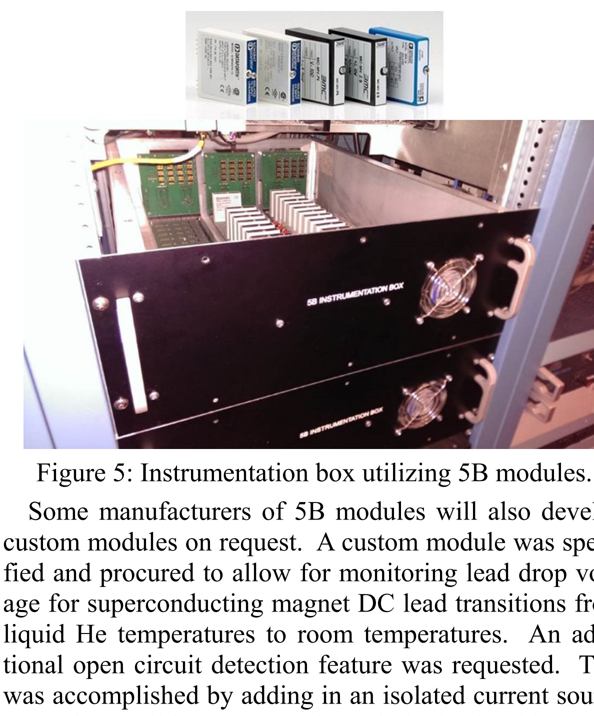

Figure 5: Instrumentation box utilizing 5B modules.

Some manufacturers of 5B modules will also develop custom modules on request. A custom module was specified and procured to allow for monitoring lead drop voltage for superconducting magnet DC lead transitions from liquid He temperatures to room temperatures. An additional open circuit detection feature was requested. This was accomplished by adding in an isolated current source to send a small loop current through the lead. This causes the voltage to reach a maximum voltage reading when the cable is disconnected, which will in turn trigger an appropriate interlock.

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Overall, this design provided a flexible, low cost per channel, high density solution which can very easily accommodate late design changes without impacting rack space.

PROJECT MANAGEMENT CHALLENGES

Concurrent Design and Construction

The FRIB project incorporated an early building construction schedule. The early building construction resulted in early completion of the front end of the facility allowing for technical equipment to be installed ahead of the building occupancy. This in turn allowed beam to be produced in the front end, months ahead of the baseline schedule. In addition, a great number of accelerator components such as cryomodules and magnets can be installed into the tunnel immediately after their completions, requiring little storage space.

On the other hand, in order for this to be successful, many departments needed to provide infrastructure requirements prior to completing the building design. Information such as number of racks required, layout, cable counts, conduit size, and power requirements all needed to be furnished. In many cases the technical designs had not finished a 60% design review, and some R&D efforts needed for the project were still working in the proof of concept stage.

To accommodate the need for design input for the building, test setups of proposed rack rows, cable trays, conduits and cables were developed to ensure adequate room was being requested within the building. Controls also developed flexible designs with minimal space impact to accommodate later design changes. (See Superconducting Cryomodule Instrumentation section above.) This resulted in an increase in labor due to additional design iterations.

System Requirements

One of the larger challenges for the control system is integrating hardware from other systems that have not completed the design process, or vendor selection process. To minimize these unknowns, the FRIB's design process utilized common tools such as interface control documents, requirements documents and design documents to detail the intended design and interfaces. Controls designs were made to be flexible to accommodate unforeseen changes. In an effort to improve communications, controls would join interfacing systems weekly design meetings. Participating in weekly meetings allowed for input into their design that could otherwise have adversely affected controls. The results of this effort was that only minor design changes were encountered which could be easily accommodated with current hardware solutions: For example a closed contact on a relay was needed versus a 24 VDC signal to implement a device enable command, or a thermocouple for a temperature sensor when an RTD was specified. The modules procured could accommodate either sensor.

One area for future improvement involves the interfacing device procurement process. Controls would often have input into specifications going out for procurement bids. However, controls should also have additional input into the final procurement selection for interfacing systems hardware. Efforts to facilitate cost reductions in the bids, sometimes caused small changes to control system designs increasing material and labor costs.

R&D Test Stands

The FRIB project had several areas where due to the increased beam power, test stands were implemented for applying new technologies or acceptance testing of cryomodules and superconducting magnets. Some of the test stands developed over the course of the project are: lithium charge stripper, superconducting magnet testing, SRF cryomodule test bunkers, and target/beam dump test stands (see Figs. 6-7). The controls effort for test stands were not included in initial baseline budgets, and/or were underestimated in the budget of the test stands themselves, as R&D efforts can be difficult to predict final completion.

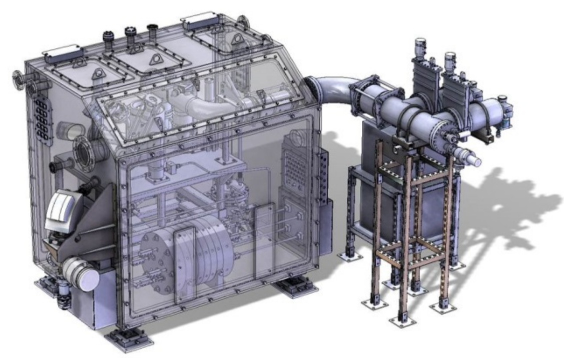

Figure 6: Lithium charge stripper test stand.

Figure 7: Target system rotation test stand.

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As the demand for test stand controls support increased, additional permanent and contract engineers were hired to meet the need. Although the labor had not been adequately estimated in the baseline, the use of more standard industrial control solutions such as PLCs common to local industry, greatly increased our ability to quickly recruit and hire engineers already familiar with much of the technology being used at the FRIB.

In future projects, the ability to plan for dedicated resources for the full length of time the R&D test stands are in use would be the preferred solution. This however can result in inefficiency as the resource could be underutilized when test stands need changes outside of controls systems. One option to make use of this underutilized time could be used to assist the main project goals, possibly delivery those ahead of schedule as time allowed. The highest priority of the resource should remain the assigned test stand. By assigning permanent resources to a system it helps develop a sense of ownership for the system, improving customer relationship and the job satisfaction. To dedicate this resource however requires additional labor budget, and should be considered in planning for future test stands for large projects.

CONCLUSION

Developing an integrated control system for the FRIB presented several challenges. Several solutions were discussed ranging from process improvements with software to more unique hardware solutions. Use of standard control function blocks, and percent error for PID loops allowed for decreasing implementation time, and improved flexibility for the cryoplant control system. The new robotic high pressure rinse system reduced labor effort, and improved the process overall. The design of the instrumentation box using commercial 5B modules reduces labor and improves flexibility to adapt to late design changes.

Project management issues were also discussed demonstrating successes such as early installation and beam delivery, through building test setups, and completing portions of the design early to allow informed design decisions. System requirements and interfaces which were well documented and regular communication with interfacing departments reduced large scale surprises. However improvements could be made by controls having input on final hardware selection for interfacing systems. Lastly, increased demand for controls support for test stands were accommodated through hiring additional contract/permanent engineers. They were able to ramp up quickly due to the use of technologies common to local industry. The project management challenges were met, but future projects may want to factor in the additional controls labor required due to various project decisions.

REFERENCES

[1] I. Malloch, et al., "Design and Implementation of an Automated High-Pressure Water Rinse System for FRIB SRF Cavity Processing*", in Proceedings of LINAC2016, East Lansing, MI.