The ISAC Control System – Phase II

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ABSTRACT

Phase II of the ISAC radioactive beam facility adds a superconducting Linac and a second experimental hall to the existing accelerator [1]. This addition will increase the size of the EPICS based control system by approximately 50%. The upgrade is done in parallel with beam delivery in ISAC-I. The paper will describe the control system additions and focus on the enhancement and web-based integration of tools used by the controls group.

INTRODUCTION

TRIUMF is currently installing phase II of the accelerator complex for the ISAC radioactive beam facility. A superconducting linear accelerator (SC Linac) is being added to the existing Radiofrequency-Quadrupole / Drift-Tube-Linac combination. This addition is scheduled in two stages:

- Stage A adds a transfer beam line, the first half of the SC Linac (consisting of 20 medium-beta superconducting RF cavities in 5 cryo-modules), and a beam-line supplying one experimental station. Of this stage, the transfer beam line and part of the SC Linac have been commissioned recently, the remainder is being installed at the time of writing. First beam with energies of up to 4.5 MeV/u is expected by the end of 2005.
- Stage B will add an additional 20 high-beta RF cavities in 3 cryo-modules as well as several beamlines for different experiments by the end of 2008. This stage will produce beam energies of up to 6.5 MeV/u.

Figure 1 shows the layout of phase A compared to the existing ISAC-I facility. This paper is concerned with stage A only.

CONTROL SYSTEM OVERVIEW

The controls for the ISAC-II systems will be fully integrated with ISAC-I and with operations from the same control room consoles. The additions follow the ISAC-I model, but include minor technology upgrades. As a reminder, a short summary of the ISAC control system architecture is repeated in the next paragraph. More details can be found in Refs [1][2].

Control System Scope and Architecture Summary

The scope of the ISAC control system includes control and machine protection for all beam optics elements, beam diagnostics devices, and vacuum systems, as well as the operator interface to the RF control stations. With the addition of the SC Linac, this scope expands to include the control of the

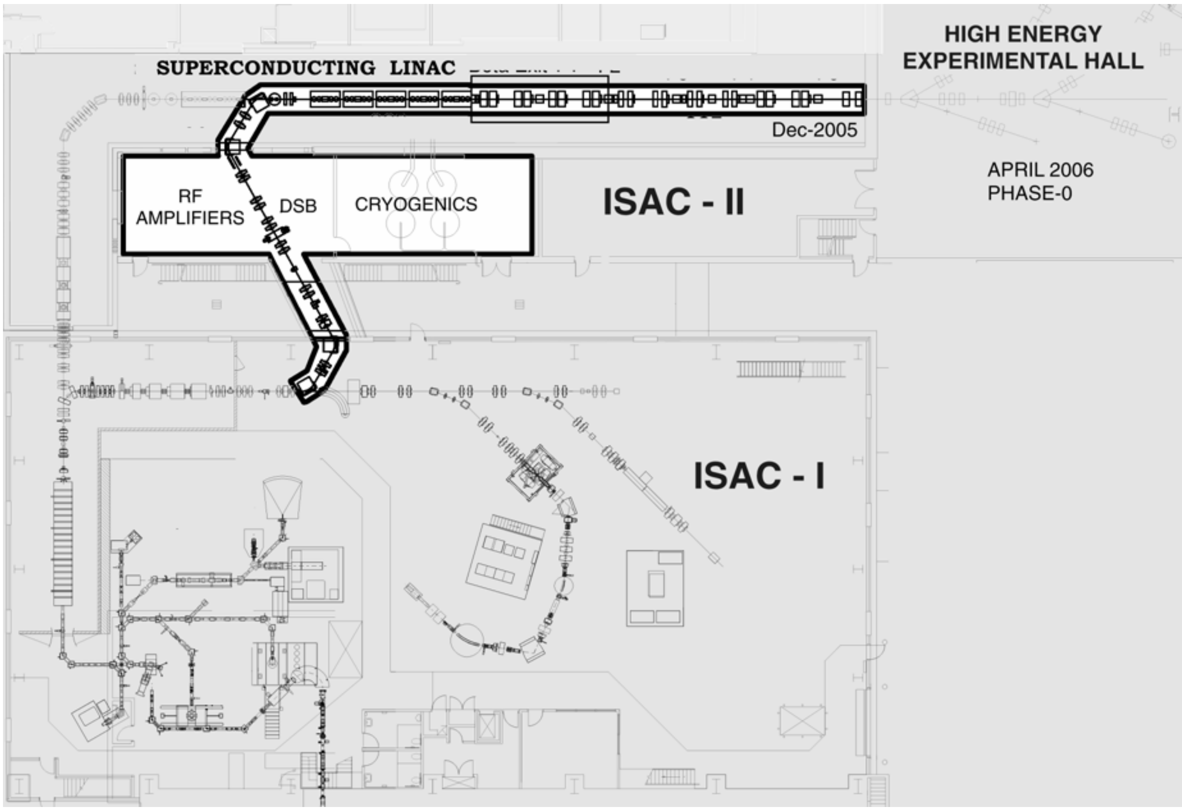

Fig. 1: ISAC-II phase A compared to ISAC-I. Only 25% of the new experimental hall is shown

distribution systems for liquid Helium and liquid Nitrogen, the monitoring of the liquid Helium plant, and supervision of the control system for the ISAC buildings.

The ISAC control system software is based on the EPICS control system toolkit. Within this framework, a “standard model” architecture is implemented. It consists of peer nodes distributed on Ethernet, comprised of Sun workstation servers, VME based input/output computers (IOCs), PLCs and Linux console computers.

The Input/Output (I/O) hardware consists of several subsystems:

- Beam diagnostics devices are controlled via VME modules in order to maintain tight coupling with the IOC CPU [3].
- Beam optics devices are equipped with intelligent local controllers, which are supervised by the IOCs. These controllers are distributed on CAN-bus networks [4].
- Vacuum devices are controlled by Modicon Quantum series PLCs, which are peer nodes on the controls Ethernet. Functionally they rank below the EPICS IOCs and are supervised by those IOCs using the Modbus protocol on TCP/IP.
- Some “special” devices use Ethernet based GPIB interfaces
- RF control stations are VXI based and run different flavours of Windows. They are peer nodes on the controls Ethernet and are designed by the TRIUMF RF controls group [5].

PHASE IIA ADDITIONS

Due to the installation of the SC Linac and associated new subsystems, the number of directly controlled ISAC devices increases to approximately 2800 and the number of supervised RF control stations increases t 21. The control system contains now 29 IOCs, which interface to 7900 digital and 4300 analog hardware channels, as well as 69 motors. The EPICS runtime databases has grown to a total of 85000 records.

The new ISAC-II IOCs are a more powerful generation of VME CPU boards [6] based on the Intel Pentium chip. No major software work was expected for this upgrade, with the exception of adapting the EPICS CAN-bus drivers to work with CAN-bus interfaces in PCI mezzanine card form factor.
As it turned out – due to problems with the VxWorks 5.4 network stack - significant work was required to upgrade the manufacturer's BSP to VxWorks 5.5 as support for this version was not available. A similar problem was encountered with the VxWorks BSP for the PC104 IOCs.

The integration of the Windows2000-based ISAC-II RF control stations with the EPICS control system was improved by replacing the RF group's network protocol. An initial attempt using the EPICS portable Channel Access server framework had reliability problems on the Windows platform. It was replaced with a "soft" IOC from EPICS release 3.14. A dynamic link library was added to the soft IOC, which interfaces to the RF applications with shared-memory and a simple API for data exchange. This solution proved to be much more stable and will be retro-fitted to the ISAC-I RF stations in the future.

The Helium liquefier plant, which supplies the SC Linac, was delivered with a commercial control system, based on a Siemens S7-400 PLC. In order to integrate this system with ISAC controls, driver software for EPICS was developed to support the Siemens FETCH/WRITE protocol over TCP/IP.

The services of the ISAC building are controlled by a commercial system based on the BACNET standard [7]. The PC-based operator interface for this system has reliability problems and lacked long-term data archiving capability. It was also felt that the operator interface and alarms for this system should be integrated with the ISAC control system. Therefore resources were diverted to develop an EPICS interface for BACNET. This effort is reported elsewhere in this conference [8].

SYSTEM EVOLUTION

Infrastructure

A new generation of Sun file servers were installed to replace the ageing, but still very reliable first generation, which dates back to 1997. "Hot" spares were implemented, which allow server switchover within minutes, should a server failure occur.
The ISAC operations console was improved by adding more multi-display Linux workstations. The role of these workstations was changed from being used as mere X-terminals to locally running their own copies of the EPICS display manager dm. This removed considerable load from the Sun servers, which are now mainly used for file-serving, data logging and archiving.
The cost effectiveness of Linux servers has led to greater adoption in the ISAC control system. Users have been moved off Sun Solaris servers onto a single Linux server that has "hot" spare redundancy. Since each client connection consumes IOC resources, a channel access (CA) gateway is utilized to serve the many dm users allowing for both reads and writes. The gateway code was modified to trap write values in a gateway put-log. A bug in the portable CA server required a patch to the EPICS R3.13.10 to allow high frequency write-through using the gateway.
In order to reduce cross-coupling between different ISAC sub-systems, several inexpensive IOCs in PC104 form factor were installed, each of them being dedicated to the supervision of one PLC. This made it easier to schedule IOC software maintenance and installation of new features.
The "soft" EPICS IOC implementation on Windows, which was used to integrate the RF stations, has provided a means of allowing other groups to develop on operating systems of their choice, while

still providing relevant signals to the commissioning and operations staff via EPICS. Initial results are encouraging, but the long term reliability of this system is yet to be determined.

Due to the presence of different, more unpredictable operating systems on the controls network, as well as the susceptibility of some legacy systems to unknown and possibly excessive network traffic, the ISAC controls network was split into a primary and a secondary sub-net connected via a Linux firewall.

The primary sub-net contains all VxWorks based IOCs, the control room operator consoles, file and application servers and the operations web servers. Access to this subnet is restricted, the Ethernet level allows IP/ARP only, IP addresses are limited to TRIUMF network and port access is tightly controlled.

The secondary controls network contains all non VxWorks IOCs (currently Windows only), access is restricted to TRIUMF only, but firewall rules are more relaxed to allow remote monitoring, backup, and updates of the Windows computers

Software Tools and Quality Control

The management of IOC software was reorganized in order to avoid cross-dependencies between different IOCs and to gain the ability to undo software changes on a per-IOC basis. Each IOC boots from its own area on the boot server disk. This boot area contains all files, which are loaded into the IOC including VxWorks kernel, EPICS object modules, etc. A Perl tool, BootConfigure.pl, was developed, which

- loads the boot area based on information in the IOC's startup script
- saves the current boot area for later reuse
- allows rolling back to previous IOC configurations
- provides reporting functions

The role of the controls group's relational database system (RDB) and associated web-application was greatly expanded. The web-application serves now as an umbrella, under which all scripting tools used by the developers are integrated. The following tool functionality is accessible through the web-application:

- Device instantiation out of the RDB to generate Capfast schematics and EPICS run-time databases
- Generation of device control screens with dynamic interlock display. Interlock information is extracted from PLC program code
- Verification of interlock implementation in PLC code against interlock specification captured in the RDB.
- Generation of bypass and force summary screens and EPICS run-time databases
- Generate html documentation of VME channel assignments
- IOC boot configuration and roll-back

The RDB automatically captures events such as file moves to the production areas, ioc boot configuration changes, etc. in order to help with post-mortem analysis of system problems.

A large Quality Assurance module was added to the web-application / RDB, which tracks engineering requests, specifications, documents, developer tasks and comments.

OPERATIONS SUPPORT

Bypasses and Forces

The ISAC control system allows both the bypassing of device interlocks and the forcing of certain device states in software via the operator interface. New tools were developed which restrict access to these features to operations staff and capture information about bypasses and forces in a database. These tools are integrated into the standard operator interface.

Electronic Log-Book

Since ISAC is a relatively new facility, an electronic logbook (Elog) was used almost since inception. Initially, a paper logbook was kept as well, which is the status quo for cyclotron operations at TRIUMF. Once the superiority and reliability of the Elog were demonstrated, the paper logbook requirement was dropped and day to day ISAC operation was documented solely with the ISAC Elog.

The initial Elog was based on a version of the Fermi National Accelerator Laboratory Elog, which itself was based on a version from Oak Ridge National Laboratory. One of the major shortcomings was the use of text files for daily data storage and a custom markup-language for the data format. Because of this and other shortcomings the ISAC Operations Elog was rewritten using the PostgreSQL relational database for entry storage. Other additions included user authentication against a central database and the capability of running multiple Elogs in parallel. The entries of the earlier Elog system were parsed and added to the new database. This upgrade made makes viewing, and more importantly searching, of the entire ISAC Elog fast and easy.

Electronic Non Conformance Reporting

Similar to the Elog, the controls group had implemented an electronic Non Conformance Report (NCR = Fault) system for ISAC. As a consequence of changes to regulatory requirements, the NCR system was upgraded to use the same RDB and coding system as the Elog. The operations NCR system is interacting automatically with the controls group's web-application, which tracks NCRs at a more detailed level than what is required for the operations group. Work has started to also couple the NCR system with the Elog. for auto-logging NCRs.

COMMISSIONING AND OPERATION

The ISAC facility has been delivering production Radioactive Ion Beams for several years. The facility, however, is always in a state of change, with new experiments and beam-lines continuously coming on-line. The installation and commissioning of the SC Linac takes place in parallel with beam being delivered to experiments from ISAC-I. As commissioning of ISAC-II with beam requires beams from ISAC-I, the commissioning schedule has to be interleaved with normal beam production in order to minimize the impact on the experimental programme. Although the new controls were implemented on the existing controls network, the operator interface for commissioning user interface was split off and operated from geographical locations closer to the systems involved. Commissioning staff was also given access to the standard ISAC controls to allow setup of the feeding ion beams.

In the production environment, write access to EPICS process variables is tightly controlled via the EPICS infrastructure. However, write access on the new systems will only be implemented after commissioning. At this point the split operator interfaces will be merged.

ACKNOWLEDGEMENTS

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