CANADIAN LIGHT SOURCE STORAGE RING RF SYSTEM

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Abstract

The Canadian Light Source (CLS) selected a superconducting RF cavity based on the Cornell design for the CLS storage ring. The RF cavity, amplifier and cryogenics plant were purchased commercially while overall system integration was performed by the CLS. The CLS also took on the design and construction of the low-level RF (LLRF). This paper discusses the CLS experience including: the design of the RF cavity control system, obstacles encountered during integration and solutions implemented or proposed to address them.

INTRODUCTION

The Saskatchewan Accelerator Laboratory (SAL) operated from the 1960s to the late 1990s when the pulse stretcher ring was decommissioned and the accelerator was reconfigured as part of the injector for a new 2.9 GeV third generation synchrotron light source.

The initial design was to use a number of conventional cavities to achieve an accelerating voltage of 2.4 MV. The direction changed in 2000 to go directly to a single superconducting cavity based on the Cornell design. An additional cavity may be added to achieve a stored beam current approaching 500mA.

A standard tender process was undertaken to procure the main storage ring components; the cavity, RF amplifier and cryogenics plant, with the CLS electing to build the low level RF (LLRF) and perform the integration of these components.

In general, CLS indicated preference for use of off-the-shelf, commodity hardware over custom or proprietary offerings. Because of its small staff relative to other facilities of this nature, the CLS has taken a more industrial approach to solutions than one of research and testing.

CLS has gained valuable operational experience over the last two years and is bringing that to bear on a redesign of the RF controls for both the Booster Ring (BR) and SR RF systems. Focus will be on tighter integration, streamlining the current installation, more sophisticated algorithms, improved elegance at the operator level as well as bringing the existing documentation up to date.

SYSTEM ARCHITECTURE

Major Systems

- Superconducting (SC) Cavity

A solid niobium (bulk Nb), 500 MHz, SC cavity was supplied by ACCEL Instruments GmbH. CLS specified the use of Siemens PLCs for any control that allowed lag times on the order of milliseconds. ACCEL complied by providing two S7-300 series Siemens PLCs, one for monitoring and one for handling equipment protection functions. The planned redesign of our existing installation will likely use a single CPU to make room for additional I/O cards, which will in turn replace other more exotic hardware.

Two GFK controllers were delivered with the cavity. The functionality provided by one of them has been moved to one of the PLCs and the controller removed. The second, a set of six PID control loops, will be implemented in PLC software in the near future, reducing the number of components to maintain, centralizing control functions and decreasing CLS reliance on proprietary hardware and allowing easier integration of the PID process variables with EPICS. Other components have been identified for replacement either by commercial products or software implementation.

Partial EPICS integration was accomplished during the installation, conditioning and site acceptance of the RF cavity. The ability to trend sundry process variables proved a valuable tool during this phase of the project.

- RF Amplifier

A 500 MHz, 310 kW CW amplifier was purchased from Thales. The amplifier consists of a TH2161B klystron, Thales switching power supply, waveguide components, amplifier control/protection system and auxiliary electronics. The system incorporates 350 kW, dry waveguide ferrite RF loads manufactured by AFT GmbH and a 350KW AFT circulator fitted with external water cooling.

The initial proposal from Thales included a completely VME-based control system. Here, as with the SC cavity, CLS indicated a preference for use of PLC-based hardware for “slow” control. Thales responded with a proposal utilitizing an S7-400 series Siemens PLC which could obtain status information from the Interlock Control System (ICS) serially over 3964 (R). The realization of this change resulted in a cost decrease, which CLS accepted.

There are some circumstances where the different acquisition rates between the PLC and ICS result in incongruous fault indications, especially with respect to the first fault that was detected.

The amplifier system control circuitry was modified to introduce a “slow” shutdown of the amplifier for interlocks that change the amplifier’s operating state from RF ON to BEAM ON. This eliminates the spike in reflected power (*P*r) from the cavity generated by sudden removal of RF drive to a loss-less resonator [1]. The 1 ms long, "ramped" RF shutdown prevents minor trips of the RF system from generating arcs in the waveguide and poor vacuum in the cavity; reducing secondary system trips and resulting in quicker system restarts. The "ramp" is implemented in hardware and resides in a NIM module in the LLRF NIM crate.

More significant interlocking conditions still shut the system down immediately by setting the RF amplifier mode to "STANDBY", removing the high voltage from the klystron amplifier.

- Cryogenics System

The cryogenics plant is a Linde-supplied TCF-50 liquid helium (LHe) liquefier/refrigerator. Control is carried out by code supplied by Linde in a Siemens S7-400 series PLC. The code was modified by the CLS to provide EPICS integration.

Initially, a variable frequency drive was specified on the main compressor to allow the plant to automatically be matched to the load. Through the design process, it became apparent that this strategy was incompatible with the tight LHe supply pressure stability requirements. Instead, the heater in the helium supply dewar was switched to PID loop control to regulate level and the VFD driver was configured to operate in one of three fixed modes; part (static) load (54%), refrigeration during normal operation (76%) and liquefaction (100%).

- Low-Level RF (LLRF)

The LLRF was designed, built and tested in-house. It is an analog, I/Q based system using PLC control. The CLS added code and hardware to one of the ACCEL-supplied cavity PLCs to automate continuous control of the LLRF system. The PLC provides the LLRF system with input set-points for cavity field voltage and phase, closed loop gain, operating frequency offset, tuner phase set point, and tuner dead-band. It also monitors feedback values from the system to adjust variables and validate system operating modes [2].

LLRF prototyping used Tele-Tech, 500 MHz, I/Q modules and Analog Devices amplifiers, with baseband and control circuitry constructed on standard proto-boards. The Tuner Phase Detector, Tuner Control, I/Q Voltage/Phase control, Shutdown Ramp, and Bad Orbit Shutdown modules are NIM modules, which reside in a single NIM crate in the main LLRF rack.

Remote frequency control of the HP8644B Master Oscillator is provided by PLC adjustment of a DC voltage driving the direct-coupled deviation input of the oscillator. This allows an adjustment range of +/- 5 kHz around the nominal storage ring frequency. The Master Oscillator signal is distributed directly to the storage ring RF control system and via analog fibre-optic links to the facility timing system, booster RF system, and other users.

The prototype I/Q cavity voltage/phase control provides open and closed loop control modes. In closed loop mode, it provides regulation of cavity voltage within 1% and cavity phase within 1 degree of operator specified values, with an open loop bandwidth of 50 kHz. The open loop mode is used during system start-up and for some conditioning activities.

The cavity tuner control is comprised of an I/Q cavity phase detector and local controls, coupled to the PLC. The PLC compares the set-point and actual cavity phase values as well as monitoring amplifier power, cavity field level and local control settings. If all conditions are satisfied, the PLC provides appropriate stepper motor control to acquire and maintain the desired cavity phase.

The performance of the original Tele-Tech I/Q modules used in the LLRF prototypes has proven adequate for the system. However, following discussions with the manufacturer, modified Tele-Tech I/Q modules were fabricated, delivered and tested. These provided improved performance in areas critical to the applications [3]. They were determined to be suitable for the pending redesign of the BR RF controls. Conveniently, automation for that system is handled by an S7-300 PLC which will be used in the BR RF LLRF redesign.

Currently, information and enhancements generated during testing are being incorporated into the documentation. Final circuits will be placed on printed circuit boards for installation.

System Boundaries

The original design has a number of signals sent from the cavity controls to the Thales ICS for interlocking under various conditions (i.e. Arc or Quench detection). These signals are sent back to the cavity control rack from where they originated as inputs to the cavity ready chain, which in turn is sent to the RF amplifier interlock chain, the output of which is in turn sent to the RF amplifier interlock chain. Future design will consider providing a single interlock to the RF amplifier representing the sum of all interlocks from the cavity ready chain. A mechanism to latch faults and the order in which they were detected (at least the first fault) will be implemented.

Data Networks and EPICS

A single EPICS IOC is running on an industrial, din-rail mounted PC manufactured by Kontron (formerly PEP Modular), which handles the communication with the PLCs over Profibus-DP. The Profibus protocol is performed by a Siemens ASPC2 chip mounted on a PC/104 card manufactured by Hilscher, who also supplies the source code for a Linux device driver and a TCP/IP server for configuring, monitoring and troubleshooting the Profibus network over Ethernet.

A protocol was established by the CLS and PLC code was added to enforce the integrity of data travelling between them and the IOC. The IOC software was also developed by the CLS. Rather than using simple application-driven serial commands, the Profibus card and driver provide block data transfers into and out of shared memory. The communication between the EPICS application and the PLC proved challenging due to the limited size of the shared memory buffer. Rather than mapping control and feedback points directly to shared memory, the EPICS task maps block data transfer requests into the shared memory, which are then interpreted and acted upon by the PLC. Simple request identifiers allow the application to recognize valid command responses. This greatly increases the number of data points accessible on a single PLC, and keeps the EPICS data point configuration information reasonably simple.

Critical control functions have been left to the PLCs, allowing them to continue operating autonomously in the event the IOC is unavailable. The IOC function is analogous to that of an HMI (Human-Machine Interface). CLS is currently evaluating the use of Siemen's Ethernet PLC cards and software built around either their SOFTNET or SOFTBUS offerings for Linux.

CONTROL ALGORITHM

System Startup and Shutdown

The Thales amplifier control system provides seven different operating levels or states: OFF, AUX, FILAMENT, STANDBY, HIGH VOLTAGE ON, BEAM ON and RF ON which are activated by the operator in that order for startup and shutdown of the RF. Transition to each state is governed by a series of pre- and post-conditions that must be met before leaving the current state in either direction; either up or down in level.

The first iteration of the RF drive OPI (Operator Interface) is modelled after the Thales HMI that furnishes local control. The level of detail and number of states it provides are convenient for commissioning. However, in normal operation an inordinate amount of control is left in the hands of the operator. In the interest of protecting equipment and removing unnecessary burden from operators, future design will present fewer states and options and restrict capabilities available in the control room to a subset required for normal operation. Access to more detailed control will still be available for troubleshooting and machine development, but only to system specialists.

Repetitive tasks such as setting control loop modes, initial values upon entering/exiting a given control state and incrementally ramping up the RF power/cavity voltage at start-up will be automated to provide faster response and less onerous operational requirements as well as improved machine protection.

Low Level RF

At system start-up, the voltage/phase control is set to provide approximately 5 kW CW cavity input power in "open loop" control mode. Once the cavity field/ feedback signal is established and the tuner phase detector indicates that the cavity is tuned to the desired set-point, the control loop can be safely switched to "closed loop" mode. The cavity voltage is then raised incrementally to the desired operating level. This sequence is repeated any time that RF is reapplied to the RF cavity.

The closed loop cavity phase is normally left at a stable value that provides synchronous phase with electron bunches injected from the booster ring. Operating frequency offset is adjusted as required to achieve optimum beam orbit.

The RF input to the cavity may be turned off with the LLRF Voltage/Phase Control in either "open loop" or "closed loop" mode but must initially be applied in "open loop" mode. Intentional shutdowns are done by selecting amplifier "Beam On" mode rather than "Standby" mode. This prevents high reverse power transients [1] in the waveguide by allowing the LLRF "Shutdown Ramp" to gradually reduce the applied RF power.

As with the RF amplifier interface, the LLRF operator screen offers functions useful for commissioning but unnecessary for normal operation and will be simplified in the next iteration.

CONCLUSION

Integration of system process variables in to a facility's SCADA (Supervisory Control and Data Acquisition) system provides valuable information. Integration of the various component control systems in to the facility-wide system is beneficial for the installation and particularly the commissioning phases and

Initial integration of the SR RF components has revealed areas that are well-suited to realization using conventional, commercially-available industrial devices.

Operational experience indicates that there are still varied opportunities for automating normal operational tasks and that more elegant control will simultaneously alleviate some of the onus placed on the operator and provide better protection to the installed systems.

REFERENCES

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