THE CONTROL SYSTEM FOR THE SLS SUPERCONDUCTING THIRD HARMONIC CAVITIES

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Abstract

The Swiss Light Source (SLS) has recently installed two superconducting RF third harmonic cavities. These passive cavities are self-excited, and are tuned to lengthen the electron bunches in the storage ring. This provides very high beam stability by reducing space charge effects, and thus reduces beam instabilities when operating at high beam currents (up to 400mA in our case). The control system has to provide a number of control and acquisition functions, including the monitoring of the PLC that regulates the cryogenic plant, monitoring of cryogenic distribution system, the tuning loop of the RF cavity, and vacuum control. The system uses the standard EPICS software and VME hardware used elsewhere in the SLS control system, but with new 24-bit resolution ADCs to measure the cryogenic temperature sensors. This high resolution is required due to the very low excitation currents (10µA) that can be used for the low temperature RTD sensors. Interfacing to the PLC is through a TCP/IP link over Ethernet. The system has to provide a very high reliability as the system has to run continuously, even during a machine maintenance period.

INTRODUCTION

In order to operate at a high electron beam current (up to 400 mA) at the SLS, two passive superconducting RF cavities have been installed. These cavities can be tuned to lengthen the electron bunches, and so reduce space-charge effects. The system consists of a number of parts:

- The cryogenic plant
- Liquid helium transport lines
- The cryostat containing the cavities
- Vacuum system

The cryogenic plant provides liquid helium at 4K, and comes with its own PLC for control and regulation.

CONTROLS REQUIREMENTS

The system has to provide a number of control and monitoring functions including:

- Displaying the status of all control points, locally and in the control room.
- Archiving of all critical control points for later off-line analysis.
- Generating an alarm to the operator if normal operational limits are exceeded.
- Displaying temperature trend graphs during cool-down and warm up.
- Controlling the stepper motors used for cavity tuning.
- Reading the temperature sensors.
- Dumping the beam if a major fault occurs, such cavity over-voltage.
- Operation has to continue, even during machine maintenance periods.

CHOICES FOR CONTROLS

As with any subsystem, a decision had to be made as to how closely the system should be integrated with the rest of the (EPICS) accelerator control system. As the cryogenic plant came with a Siemens[1] PLC, three choices we available:

- Provide all necessary functionality with the PLC, including operator interface.
- Have the PLC control only the cryogenic plant, and use EPICS for cavity tuning, vacuum, and supervisory control.
- Replace the PLC with a VME system running EPICS.

Advantages of a PLC only solution

As the cryogenic plant came with a PLC solution for its operation, this could be extended to encompass the other functions necessary. Only one system would then have to be maintained, and no changes would be needed to the cryogenic plant controls. The company providing the cryogenic solution would be able to maintain the system. There would be no pressure to change the system when a new version of EPICS is installed elsewhere at SLS.

Advantages of an EPICS only solution

Maintenance of an EPICS only solution would be easier, as we have all the necessary in house expertise, which is not the case for the PLC solution. We would avoid the additional complexity of interfacing to a foreign system. The SLS operators are familiar with the EPICS tools. It is easy to correlate with other control system signals.

Advantages of a hybrid solution

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IMPLIMENTATION

The hybrid solution was chosen, as it represented the least work, and had no major disadvantages.

Tuning control

Tuning each cavity involves the control of a stepper motor. This motor is of special construction as it has to operate at cryogenic temperatures. It provides some particular challenges for control as it is also not possible to fit encoders or limit switches. Furthermore the motor must not be driven to the physical limits. Therefore the only way to calibrate the motor position is to inject a signal without electron beam, and to read the cavity voltage (with an RF diode) and to find the peak voltage position. The motor is then de-tuned a known amount before injecting beam into the machine.

It is desirable to have the motors un-powered when idle, in order to extend their lifetime. For this reason an active feedback loop is not used, but a feed-forward table, of electron beam current vs. tune value. At the moment there are only 10 points in the table, corresponding to values between 300 and 400 mA. The motor amplifier is only activated and motor moved when a change between one of these values is needed.

The cavity voltages are read in parallel into the control system and the machine interlock system. If the voltage becomes too high, for instance by accidentally approaching resonance, the electron beam is switched off.

PLC interface

In order to read the status of the PLC cryogenic plant controls it was decided to use a direct Ethernet interface between the PLC and the EPICS VME crate [2]. This was done using a second dedicated CPU in the VME crate whose only function was to communicate with the PLC. In this way Ethernet traffic for this link could be separated from normal control system traffic. The data is made available in a shared memory buffer on the dedicated CPU, assessable from the VME bus. This interface appears to EPICS as a normal I/O card. A simple EPICS driver was written to access the data.

Sending temperature sensor data from the EPICS system to the PLC was accomplished using a 4-20mA interface. This was because this is critical data, necessary for the correct operation of the cryogenic control loops, and the reliability of the Ethernet interface was not known. A standard SLS analogue output card was used for this purpose, coupled with a din-rail block mounted adaptor with current source integrated circuits. This interface was the source of some difficulty when more than one link was used, as the Siemens PLC 4-20mA interface input channels are not fully isolated from each other, and so some modification had to be made to the interface to accommodate this. With hindsight, a voltage interface would have been sufficient as the distance between the two systems is short (4m).

Vacuum control

Vacuum control uses the standard SLS gauges and (analogue) interface to the EPICS system. In this was it is cleanly integrated with the rest of the SLS vacuum components. Measurements are made of both the low pressure in the cavities and adjacent beam pipe, and the insulation vacuum, which has much higher pressure.

Cryogenic temperature measurement

Cryogenic temperature measurement was done entirely in EPICS, and the values, when needed, sent to the PLC. The cryogenic temperature sensors were pre-installed in the cryostat and helium transfer lines. The sensors are of two types: Cernox RTD's for low temperature measurements and PT100's for 'high' temperatures (above 100K).

The excitation current for the Cernox devices must be very low, and in our case we used 10μA, which in turn means we are reading very low voltages. A temperature change from 4K to 300K corresponds to a resistance change of 5kohm to 50ohm. So to meet the requirement of detecting a 1K change at room temperature, we must have a voltage resolution of 10uV. At low temperatures the resistance is much higher, and so the corresponding voltage change much greater. To achieve the 0.1K resolution needed at low temperatures is therefore less of a problem.

The resistance change of the PT100s is much less (approximately 90 ohm to 110 ohm over the temperature range we use). Unfortunately groups of three sensors are wired to one connector on the cryostat, and as some connectors have both PT100s and Cernox, the same low current (10uA) has to be used for both.

The solution we use is a Hytec 8403 analogue input industry pack (IP) card. This device has 8 high resolution (24 bit) inputs and a 0-2.5V input range. It also has a two channel programmable current source we use for excitation. We wire groups of three sensors in series with a high precision reference resistor. By measuring the ratio of voltages across the reference resistor and each sensor we can calculate the sensor resistance to a high accuracy, even if we don't know the excitation current to the same level of accuracy.

The Cernox sensors are non-linear, and each has an individual calibration table. A polynomial fit is made to this curve, and an EPICS calculation record used to calculate temperatures from resistance.

FUTURE WORK

At the moment, during machine shutdown, no operators are on shift, and so a major problem, although reported by the alarm handler, may not be noticed. It might therefore be necessary to install an alarm handler console for this purpose in the technical services control room, which is always manned, or have the alarm handler send an SMS message to the mobile phone of someone from the RF group when a fault occurs (this is done for other systems). Not all internal conditions of the PLC are at the moment sent to the EPICS system, to do this will require a modification to increase the buffer size of the shared memory.

CONCLUSIONS

By adopting a hybrid solution of PLC for cryogenic plant controls and EPICS for supervisory controls we retain many of the advantages of a 'pure' system, while avoiding many of the risks. The installed system has provided very high reliability operation.

REFERENCES

[1] http://www.siemens.com
[2] Integration of Industrial PLCs into an EPICS control system, ICALEPCS2003