PROGRESS ON THE IMPLEMENTATION OF THE DIAMOND CONTROL SYSTEM

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ABSTRACT

Diamond is a new third generation synchrotron light source currently being designed and constructed in the UK. The control system for Diamond will be a site-wide monitoring and control system for the accelerators, beamlines and conventional facilities. Progress on the detailed design, procurement and installation of the control system is presented. This work includes refinement in the choice of EPICS tools, and the development of additional tools and applications. The design being realised for the control system structure, includes solutions for interfacing to technical systems, control system networking, machine protection, and the physical implementation.

INTRODUCTION

Diamond is a third generation, 3GeV synchrotron light source currently being constructed in the UK. The storage ring (SR) is based on a 24-cell double bend achromatic lattice of 561m circumference. It uses a full-energy booster synchrotron and a Linac for injection. The spectral output is optimised for high brightness up to 20keV from undulators and high flux up to 100keV from multipole wigglers. The current construction includes seven photon beamlines, with a further fifteen beamlines now approved for design and construction between 2005 and 2011.

The outline design for the control system was reviewed in [1], which presented the choice of the EPICS control system toolkit, the estimated interface requirements and the initial requirements for software applications, and indicated how these would be realised. An update of progress on the control system design was presented in [2]. This paper follows on from the above works, presenting refinements in the design, and summarising the solutions adopted for each of the technical systems.

PROGRESS UPDATE

The project is currently in a detailed design, procurement and construction stage. The building is well advanced, with initial occupancy in Nov 2004 for installation of accelerator systems and construction of beamline hutches and cabins. Installation of the Linac began in Dec 2004 and first electrons were accelerated in August 2005. The Booster and SR installation started in Nov 2004, and as of Sept 2005 50% of the Booster magnet and vacuum girders are installed, together with RF Cavities, RF amplifier and all instrumentation. For the SR, 33% of the magnet and vacuum girders are installed together with one superconducting RF cavity, the refrigeration plant and three RF amplifiers. In addition, a considerable amount of support work has been carried out in preparation for the remainder of components to be installed, including pipework, cabling and instrumentation.

The commissioning of technical systems for the Linac took place during August and early Sept 2005. This went very smoothly with the commissioning of nine VME IOCs for the RF modulators, diagnostics, PSUs, vacuum, PSS and timing, and six Libera eBPMs, together with a temporary control room. It is now planned that Booster control system commissioning will commence in Nov 2005, and that of the SR early in 2006.

DESIGN DEVELOPMENTS

This section presents refinements to the design process and tools since the previous progress report.

Application Development Environment

The development process for all VME systems is based on EPICS 3.13.9. Whilst it had been planned to standardise on one version of EPICS, this has not proved possible and EPICS base 3.14.7 is being used for the Libera eBPMs and for simulation systems, particularly a virtual accelerator with an EPICS interface. It is further planned that the beamline control systems will adopt EPICS 3.14.X and that the machine control system will then be upgraded to 3.14.X as soon as practically possible.

The development and operational client platforms have now standardised on PCs running RedHat Enterprise Linux 4.

Version Control

To date, version control has been managed through CVS [3], but initial work is now being undertaken to move to Subversion [4]. This will be front-ended with scripts to provide a controlled interface to the repository and an automated build mechanism, whereby all operational software is checked out of the repository and built in a known environment to give consistency and stability of build.

Development Model

The development model adopted has been to agree interface and equipment requirements with the technical groups for each technical system, and then, based on these requirements, to develop any required device driver support, communication protocol and a template representing each type of physical device. This template is a collection of EPICS records which provide the physical interface together with any intermediate processing. The template is then instantiated as many times as necessary, with the required addresses and process variable (PV) names. From each physical template a soft template, which replaces the hardware reference by a simulation, is created. The soft templates are then used to build a model of the technical system by instantiating them with the full list of PVs. The model, which has the same interface records and PVs as the real accelerator, is then used to build higher level tools. For Diamond this process has been applied successfully across most of the technical systems, resulting in simulation of the control system with approx 350,000 PVs being served up by twelve MVME5500 IOCs.

Virtual Accelerator and Physics Applications

To enable early testing of physics tools through the control system, a virtual accelerator has been implemented to give simulation of a linear lattice though the intended PV interface. This was developed by providing device support to interface to the model using the TRACY II libraries [5]. For physics tools the Accelerator Toolkit [6] for Matlab is being used.

Applications

For each technical system, synoptic-based views have been realised using the EDM display manager. This implementation has necessitated deployment of several new EDM widgets, including a thumb wheel control and a display for video images. The ControlDesk [7] application is being used to provide tabular displays of the control parameters.

Database design

VisualDCT [8] has not been adopted as uniformly as was envisaged for EPICS DB design. This has been partly due to usability issues, and further effort is now in progress to address known deficiencies. On the other hand, it has often proved more practical to design and implement simple database templates by hand using a text editor, and in one case database templates have been generated using Python scripting.

Consideration is now being given to embedding metadata in the EPICS DB to define the links between the PV associated with a particular record and high-level applications. These applications include ControlDesk, Archiver, Alarm Manager, backup/restore and a web interface. This data will then be used to auto-generate configuration files for these applications, thereby defining a single point of design.

Turnkey Systems

Diamond has procured a number of turnkey systems complete with EPICS based controls. These have included the Linac, Booster and SR RF amplifiers, SR low level RF, permanent magnet insertion devices (IDs), a superconducting multipole wiggler, SR girder alignment, monochromators and other beamline components. In each case, the supplier was free-issued with standard components, thereby getting consistency of hardware, together with an EPICS development environment and documentation on the Diamond application development process and PV naming conventions. This has resulted in systems being delivered that take the minimum amount of work to integrate back into the in-house development process so as to allow in-house support and maintenance.

To further encourage industry to develop the skills and to offer EPICS-based control solutions, Diamond made potential suppliers of turnkey solutions aware of its intention to ask for EPICS-based controls, and encouraged these suppliers to develop some knowledge of EPICS by making places on EPICS training courses available to them.

HARDWARE

Programmable Logic Controllers(PLCs)

Two solutions to address PLC [9] requirements have been adopted. The first requirement for a low-end units is addressed using the Omron CJ1 [10], which provides interlocking and control, e.g. for vacuum valves. The second, for high-end process control applications, uses the Siemens S7 [11] series of PLCs. The latter are being used for the Linac, RF cavity and cryoplant controls. The low-end units interface to IOCs using a serial protocol over an RS232 connection and the high-end units use the Industrial Ethernet protocol over an Ethernet connection.

Standard solutions have been developed by encapsulating the low-end PLCs in crates, for control of four vacuum valves, six vacuum valves, thermal protection and water flows for machine protection.

Physical Structure

The control system interfaces to the technical systems at 37 control and instrumentation areas (CIAs) covering the Linac, the Booster, transfer lines, plant rooms, the SR, the first seven beamlines and technical services (the building and cryogenics). For the SR there will be one CIA per cell, thereby ensuring that each cell is self-contained.

The CIAs are rooms within the building that contain the control and instrumentation. They are air-conditioned to maintain a clean and temperature-stabilised environment for the instrumentation. The CIA structure provides sound insulation, reducing the noise level in the building by reducing the contribution from fans contained in the instrumentation which is located in the CIAs.

Generic IO

Diamond Light Source selected a range of generic VME IO from Hytec Electronics Ltd [12]. This is based on VME IP carriers, IP modules, transition cards and plant interface modules. The system is very modular and allows a high flexibility and density of IO, thereby enabling most systems to be interfaced using between two and four VME modules in a seven-slot VME crate. The IP modules types include 16 bit ADC and DAC, digital IO, serial RS232 and RS4222/485, an incremental encoder, and a high resolution ADC with current source for direct PT100 and thermocouple connection. Whilst device support existed for some of the hardware, this was not well integrated into the standard EPICS model and so a programme of development, jointly between Hytec and Diamond, has taken place to refine this.

The OMS VME58 has been used for motion control on the accelerators, as it is a proven solution with the EPICS community. However, beamline requirements for synchronous control on monochromators necessitated greater controller functionality, for which the Delta Tau PMAC controller has been selected. Diamond has worked with the APS Beamline Controls Group [13] on the development of Motor record support for this controller.

Network

A fibre optic infrastructure is being installed from each of the CIAs back to the control system computer room and from there to the control room. It consists of a mixture of single-mode and multi-mode fibres using a blown fibre [14] structure, thereby enabling future upgrade. The fibres provide two computer networks, a control system network and a secondary computer network, to enable effective management of traffic on the control system network. Each network uses a central switch in the control system computer room and a further layer of switches at each CIA. One application of the secondary network will be to stream video images back to the control room using H.323 protocol. This will be used by cameras to monitor personnel access to the accelerator enclosures as part of the personnel safety system.

The fibres will also be used for event distribution, for the machine protection system, for the beam position feedback system and to realise wide band, up to 3 GHz, analogue connections to the control room. The solution being considered [15] uses point-to-point connections with direct modulation of the analogue signal on to the fibre.

TECHNICAL SYSTEMS

Linac

The control of the modulator for the Linac RF is through a number of Siemens S7 PLCs. These interface to the IOC over a network connection. All other hardware associated with the Linac, including PSUs, Vacuum, Timing etc, is managed using the standard interfaces used elsewhere on Diamond, thereby maintaining consistency.

Diagnostics

The Libera [16] electron beam position monitor (eBPM) was selected for all the electron beam position measurements. It is a network-attached device, having an embedded ARM processor running the Linux OS and version 3.14.X of EPICS. Instrumentation Technologies has provided an interface library to the signal processing hardware, on top of which Diamond has then implemented EPICS device driver support. To date this has been used successfully to measure electron beam positions on eBPMs for the Linac-to-Booster transfer line as part of Linac commissioning, but the device support is still being developed to make the full functionality of the Libera units available through EPICS.

For optical diagnostics, CCD cameras with the IEEE1394 Firewire bus have been adopted as a standard. Firewire device driver support has been developed to interface through the DCII [17] library for both Linux and VxWorks. The VxWorks version uses a commercial Firewire stack from MindReady [18] and a PMC Firewire interface on the IOC processor board. The support, at present, calculates some quantitative values for each frame and packs the frame into a waveform record. An EDM widget has been developed to display the image. A planned development is to include some level of compression on the image transfer.

PSUs

All of the 1300 PSUs used on Diamond are controlled using the SLS PSU controller [19]. Diamond bought the design rights to use the hardware and existing software from the Paul Scherrer Institut. To support the various types of PSU used on Diamond, the PSU controller DSP software and FPGA logic has been developed to support multiple inverter modules, each phase shifted to minimise ripple, parallel and series combinations of PSUs and charger operation for pulsed PSUs. The inverter modules are in an N+1 configuration enabling uninterrupted operation in the event of one module failing. As the controllers are used across the range of PSUs, they provide a standard physical interface with some functional differences. This interface is a 5MHz Manchester-encoded point-to-point serial interface over a fibre optic link which is connects to the IOC using a VME IP carrier and IP module.

Vacuum

All vacuum gauge controllers and Ion pump supplies are interfaced though serial connections in a point-to-point configuration. Vacuum valves are controlled and protected by standard valve control units encapsulating a PLC and interfaced to the IOC using a serial connection. RGA units, which are capable of being operated in a stand-alone or network mode, are also interfaced to the control system, to allow a number of predefined mass scans to be viewed and archived through the control system.

PSS

The Personnel Safety System (PSS) on Diamond is based on the Daresbury designed PSS [20] which is a hard-wired dual guard line, relay based system. Whilst the protection logic is all realised though the hard-wired relay logic, the inputs and intermediate states are all monitored by control systems. The PSS logic is realised in a crate with a G64 bus to read out module data. A VME processor running EPICS accesses the module data over a VME to G64 bridge module.

MPS

The machine protection system (MPS) manages global equipment protection, for vacuum vessel and series connected magnets (SR dipoles, Booster dipoles and Booster quadrupoles). Water and temperature are monitored on each cell using a standard PLC-based solution, which is supervised over a serial link by the IOC. The PLC does not meet the speed requirements for some of the interlock inputs, notably on mis-steered beam, and these interlocks, together with an output from the PLC are then managed by the local MPS module. Each local MPS module generates a pulse stream to the global MPS module which, subject to all local modules being good, generates a pulse stream to the source of the energy, RF amplifiers or PSUs. The local and global MPS modules are realised as VME64x transition cards and are monitored by a VME DIO board and use principles defined in the CEBAF Fast Shutdown System [21]. The VME IO board and EPICS software are not part of the protection process, but serve to manage the process.

RF and other

The Booster RF amplifier is a commercial unit using a commercial proprietary amplifier controller and interfacing into the IOC over a serial link. The Booster RF and low level RF use analogue signal processing and are controlled using DACs, ADCs and digital IO. Control of each of the SR amplifiers is performed by an associated IOC, which interfaces to the amplifier through generic VME IO.

The 72 girders which make up the SR each have 5 degrees of freedom driven by motorised cams which are controlled by OMS VME58 controllers. Other hardware associated with the girder positions is managed through the standard VME IO.

Each of the first nine permanent magnet IDs is also controlled by OMS VME58 motion controllers, together with a PLC subsystem to define a safe operating window and hence protection of the structure. Other instrumentation associated with the IDs are managed though the standard solutions.

Event System

The timing system [22] uses a new version of event generator and receiver modules, based on the principles of the APS and SLS event systems, which have been developed by Micro-Research. The new versions have increased functionality and are realised as VME 64x modules for both generator and receiver, and also as a PMC module for the event receiver. The EPICS support for these has been developed to support the improved functionality of the VME modules and to add support for the PMC variant. This has included a new scheme to distribute and increment time across the Event System.

Fast Orbit Feedback

The choice of the Libera eBPMs has directed the design of the Fast Orbit Feedback System to stabilise the electron beam in the SR. The data from the 168 eBPMs is required to be moved into the 24 VME processor cards, which will carry out the feedback processing to update the corrector PSUs. This requires a low-latency high-bandwidth data path which is being realised by connecting the Libera units and the computation nodes using the high-speed serial interconnects known as Rocket IO available on the Xilinx FPGAs. The interconnection is being realised over a fibre optic link and a custom communication controller designed and implemented in VHDL to realise the data transfer [23].

Beamlines

EPICS is further being applied to the control of all instrumentation for the photon beamlines on Diamond [24]. Consideration is now being given to integrating detectors and other experimental components with EPICS.

CONCLUSION

The design for the Diamond control system is now defined and the project is in an implementation phase. EPICS has been applied to integrate all accelerator-related technical systems and is now being applied on to the beamline and experimental stations. The implementation mainly follows the historical EPICS architecture using VME and VxWorks, but also makes benefit of the recent development of versions to operate on other platforms and OSs. Great benefits have been realised from the stable nature of the core components of EPICS, IOC processing and communications, enabling resources to be concentrated on the task in hand.

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