IMPLEMENTATION, COMMISSIONING AND CURRENT STATUS OF THE DIAMOND LIGHT SOURCE CONTROL SYSTEM

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Abstract

Starting with the Linac in 2005 the commissioning of the Diamond Light Source accelerators and photon beamlines, together their related control systems, progressed to an aggressive programme such that as of early in 2007 the facility was available for first users with a suite of beamlines and experiment stations.

The implementation and commissioning of the control system to meet the overall project objectives is presented. The current status of the control system and including ongoing developments for electron beam orbit stability, and future photon beamline requirements are also described.

INTRODUCTION

Diamond, a third generation 3GeV synchrotron light source[1], commenced operation in January 2007. 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 multi-pole wigglers. The current operational state includes seven photon beamlines, with a further fifteen beamlines now under design or construction.

Progress in the design and initial implementation for the control system was presented in [2]. This paper follows on from the above works, presenting refinements in the design, the implementation, and overall commissioning.

CONTROL SYSTEM IMPLEMENTATION

The Diamond control system is based on the EPICS control system toolkit. For the accelerators and initial 7 beamlines, the Input output controllers (IOCs) are ~267 VME VxWorks systems together with 202 Libera eBPMs running on ARM processors under Linux and a further 10 soft IOCs, running on blade PCs under Linux. The IOCs are structured by technical system and by geographical location. Linux PCs are used for all servers and operator interfaces.

Most user applications have been developed in EDM, with some new widgets developed including a video display component. Physics tools are based on the Accelerator Toolbox (AT)[3] in Matlab and other Matlab applications. Good use has been made of Python QT for client applications that require a degree of client side processing, and for general purpose scripting.

While the technical subsystems are very much as previously reported, of particular note are; the 1200 PSUs, (including pulsed PSUs), all use the same digital PSU controller[4], eight variants of software and FPGA logic were developed to accommodate the different topologies. The EPICS interface to Libera[5] eBPMs, was developed in-house, providing multiple data sets of high quality diagnostic data, from early on in the commissioning process. The high-degree of integration of the technical systems, MPS, PSS, vacuum, radiation monitors and environment, has provided benefits in cross system data correlation.

Machine Protection System

The protection of equipment is realised through a Machine Protection System (MPS), which provide fast sub 600usec beam dumps by switching off the RF when a critical interlock fails. These include the 672 invalid orbit interlock calculated in the Libera eBPMs and other critical interlocks where component are exposed to high beam powers, up to 50kW. A further 456 slow interlocks from water flows and temperatures are processed through PLC sub systems in to the MPS.

Timing System

A single timing system[6] developed from APS/SLS event systems, is distributed to all VME IOCs. It is used for all timing functionality including Linac gun, RF, diagnostics, PSUs, and synchronisation clocks of the distributed systems.

Networking

The fibre infrastructure serves the computer networks, timing, and MPS systems. The computers networks include two physical networks, the Primary Network for all operational control systems and Secondary Network for all other functionality. The primary is not routed to the site Primary Network but a number of Channel Access Gateways are used to provide accelerator PV access, in offices and on photon beamlines.

Personnel Safety System(PSS)

The PSS was designed against the IEC61508 standard for the design of Electrical Electronic and Programmable Electronic Safety-related Systems and the required functionally to meet the UK Ionising Radiation Regulations. The implementation is based on hardwired dual guard lines system[7] with all processing realised in relay logic. Control system monitoring of all inputs and outputs provides for valuable diagnostic capabilities together with the compilation of operation statistics to validate the design model.

Development Model

The development model adopted has been to agree interface and initial functional 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. From each physical template a soft record template, which replaces the hardware reference by a simulation, is created. The soft templates were then used to build a model of the technical system by instantiating them with the full list of PVs. This gave a simulation of the control system with approx 350,000 PVs, served up by twelve MVME5500 IOCs. The simulated system and application were then evaluated with the technical groups to understand and refine the functional requirements. This process of working closely with the technical groups continued through initial commissioning and into operations.

To enable early testing of AT for Matlab and the Diamond implementation of the Middle Layer interface to the control system, a virtual accelerator was implemented to give simulation of a accelerators through the final PV interface. This was developed by providing EPICS device support to interface to an accelerator model implemented using the TRACY II libraries [8].

Application Development Process

The application development process, originally based on CVS but is now being migrated to Subversion, has two classes of released software. A ‘Work’ release is used only for testing, not for operational subsystems, and of which there is only one version and a production or “Prod” release for which every release is uniquely versioned and preserved. With all releases to the Prod structure preserved it is quick and easy to role forward to test a new release or to role back on discovering a problem to an old release. This has contributed to ensuring high-levels of control system availability.

Resources and Procurement

Accelerator vacuums, diagnostics, PSUs, Timing, Front-ends, PSS monitoring, together with Beamline vacuum, diagnostics and most motion control systems were delivered by the in-house team while the Linac, Booster and SR RF, insertion devices, SR LLRF, girder alignment, optics for 3 beamlines, and three further monochromator control systems were delivered as part of turn-key contracts with EPICS controls. The suppliers of turn-key systems were free-issued with standard components, thereby getting consistency of hardware, together with an EPICS development environment and documentation on the Diamond application development process. This was very successful resulting in all the above system being successfully delivered and commissioned by industry.

ACCELERATOR AND BEAMLINE COMMISSIONING

Injector

Commissioning of control 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 eBPMs. The Booster control system commissioning commenced in Nov 2005, with a similar number of IOCs and first circulating beam being achieved in Dec 2005.

Linac and Booster were commissioned and initially operated through a temporary network and from a temporary control room. The installed network was handed over in March 2006, so enabling future commissioning to take place from the final Control Room.

Storage Ring

Control systems commissioning of the SR commenced in January 2006 with a programme of commissioning all required technical systems at two cells per week. This programme was maintained despite difficulties relating to the building being incomplete and late delivery of network. This was only possible at this rate as due to the stability of the control system initial releases, which came from system tests, testing of overall functionality, and high-level application testing against simulation systems. By May 2007 all vacuum, PSUs, Timing, and diagnostics controls were available ready for first beam commissioning.

During the period May to July first beam commission was undertaking into the SR at an energy of 600MeV because no cooling was available from the building. Control system functionality was good and in the 4 week campaign accumulate beam was established.

Installation and control system commissioning of narrow gap vessels, insertion devices and photon front-ends resumed during the period July to August. With cooling available, beam commissioning commenced in September at 3GeV, and stored beam was achieved in a few days. Machine protection system and safe orbit interlocks were then commission enabling beamline currents to 60mA to be stored in early October. Beam based alignment, to establish actual BPM to quad offsets and LOCO based correction of the optics were then applied to achieve the design operating parameters of the SR. Slow orbit correction, with the model response matrix, was then routinely used from Oct to maintain orbit stabilities around 20um rms.

Photon Beamlines

The optic controls for three beamlines and monochromators for four further beamlines were commissioned as part of turn key contracts. All other beamline controls were delivered and commissioned by the in-house team.

First light into a beamline was achieved in Oct 2006 and first users in January 2007. By Sept 2007 seven beamlines had had carried out user experiments. During this period further work continued in control system commissioning and integration of the high-level applications.

CURRENT STATUS

Operation

During 2007 Diamond will deliver 3000 operational hours, to date with 92% up time. From January to September there was a limited user programme and ongoing photon beamline commissioning, with a full user programme on 7 beamlines commencing in Sept. User hours will increase by 1000 hours per year to 6000 in 2010, with the number of beamline increasing to twenty two by 2011.

Fast Orbit Feedback

Commissioning of the fast orbit feed back [9] to stabilise the centre of mass of the electron beam has been ongoing during 2007 with routine operation commencing in August. RMS orbit stabilities of <200nm at DC and <1um over a BW 1kHz have been achieved. While these do not currently meet the requirement stability of 10% of beam dimensions, further work in characterisation and tuning is expected to achieve this.

Top-up Operations

Top-up, injection of charge every 2 minutes with photon shutters open, to maintain a beam current within 0.3% stored current, is progressing. The functionality in the PSS to permit this have been approved and application software to monitor the acceptable operating widow to maintain top-up operation have been developed and gating signals, distributed through the Timing System to beamlines, agreed. While testing of the Top-up operation has been carried out, routine operation is now subject to completion of analysis of possible failure modes and completion of the safety case.

FUTURE DEVELOPMENTS

Control System

At present the accelerator parts of the control system use EPICS 3.13 while the photon beamlines use EPICS 3.14. Currently work is in progress to migrate all modules and systems to EPICS 3.14. As part of this development progress will use an auto build and release environment for all production modules, thereby ensuring consistency of build.

Photon Beamlines

The current programme of beamlines utilise around half the capacity of Diamond. Science proposals are currently being developed for a 3rd phase of beamlines to be constructed a two per year from 2011. Solutions to deliver temporal beams in the x-ray spectrum are being considered, possibly by operating the SR with a low alpha optics, or by laser slicing of the electron beam.

CONCLUSION

The control system for Diamond has met its requirement in terms of technical performance and importantly initial availability and subsequence stability. Even with some level of commissioning overlapping between the control system and system being controlled it was there as a service to support commissioning of the accelerators and beamlines.

There have been clear benefits from the technical system and geographical division of the control system sub systems, in that there was very little disruption of an already commissioned system by other systems being commissioned. The larger number of smaller systems does make commissioning easier and more effective. The ability to commission systems off-site and integrate with virtually zero overhead was particularly valuable for turn systems.

The use of modular design, reuse of code and implementation by configuration made for a robust system design, and good subsequent management. The use of the vertical tests and simulation early in the design process gave high levels of confidence in the final application software. All of which built on the stability of the EPICS toolkit.

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