CONTROL SYSTEM DEVELOPMENTS FOR THE DIAMOND LIGHT SOURCE DDBA UPGRADE

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Abstract

Upgrading one Double Bend Achromat cell to a Double Double Bend Achromat (DDBA) cell in the Diamond Light Source storage ring [1] necessitated a broad range of changes to the overall control system. These changes included developments to the interface layer of the controls system to incorporate changes to the underlying instrumentation, associated development of user interface, changes to real-time feedback and feed-forward processes and to the online accelerator model. Given the pressures to minimise the shutdown length, the control system developments were optimised for time effective installation and commissioning. This paper outlines the control system developments for DDBA, the management process and lessons learnt from this process.

INTRODUCTION

The Diamond Light Source (DLS) storage ring (SR) was commissioned in 2006 with a 24-cell double-bend achromat (DBA) design that allowed for a maximum of 22 straights available for insertion devices and 24 bending-magnet beamlines. The original lattice had a six-fold symmetry, but this was broken in 2009 by the introduction of two so-called mini-beta cells for customized optics. Having used all the available spaces for new insertion device beamlines, the DDBA upgrade allowed for installation of one further insertion device in a location that previously would have been available only for a bending magnet beamline. This is shown in Fig. 1.

The lattice change required replacing all of storage ring cell 2 with newly-designed magnets, diagnostics and vacuum vessels, based on a two girders as opposed to the original three. The new insertion device would be installed during a later shutdown. Each of the new components required new or adapted control system software, using the EPICS toolkit. The changed optics placed entirely new constraints on the behaviour of the storage ring, and so the accelerator model was changed significantly and the machine needed recommissioning. Global software systems such as feedback and Topup needed adapting to the new model and the new hardware interface.

All of these changes were successfully achieved during a carefully-planned 8-week shutdown at the end of 2016. This paper covers the control system changes required for this project.

CONTROL SYSTEM COMPONENTS

Power Supply Controllers

The SR magnet power supplies at DLS are typically controlled from two EPICS Input-Output Controllers (IOCs) per cell. The new DDBA configuration contained a number of new magnets resulting in the installation of a third IOC. Each new magnet was added to the control system and the user interfaces. Some of the magnet controls have additional capabilities to support feedback and feed-forward systems; all of the new magnets of these types were given these capabilities to allow maximum flexibility in future.

Personnel Safety System (PSS)

DDBA required only minor amendments to the PSS logic in two sections. A short logic chain was added to the SR cell 2 PSS crate, taking interlocks from the SR dipoles and new quadrupole power supplies to generate the "DDBA AT FIELD" permit. This permit feeds into the logic chain for the "SR READY" permit, which is contained in the one of the crates in another SR cell. This permit is required to enable the Linac and SR to operate.

Machine Protection System (MPS)

The MPS functionality was kept broadly the same as before but with the addition of extra permits for the four new dipole trim magnet coils. This was achieved by taking a TTL output from the local MPS card and fanning it out via a signal conditioner and relay. It was also recognised that due to the smaller size of the the vacuum vessel more thermal monitoring and interlocks were required. The temperature and flow monitoring were managed via PLC-controlled remote IO modules installed locally in the tunnel. All critical thermal and flow interlocks were managed by cabling back to the local MPS rack to backplane-based core IO before being collated and forwarded to the local MPS card. Local signals from the vacuum and diagnostics subsystems were connected directly to the local MPS card.

Vacuum

The bakeout for the DDBA vacuum module required careful consideration and design. Due to parts with differing thermal mass heating and cooling at differing rates, to avoid damaging flange seals and other components, it was therefore critical that temperature changes were uniform across

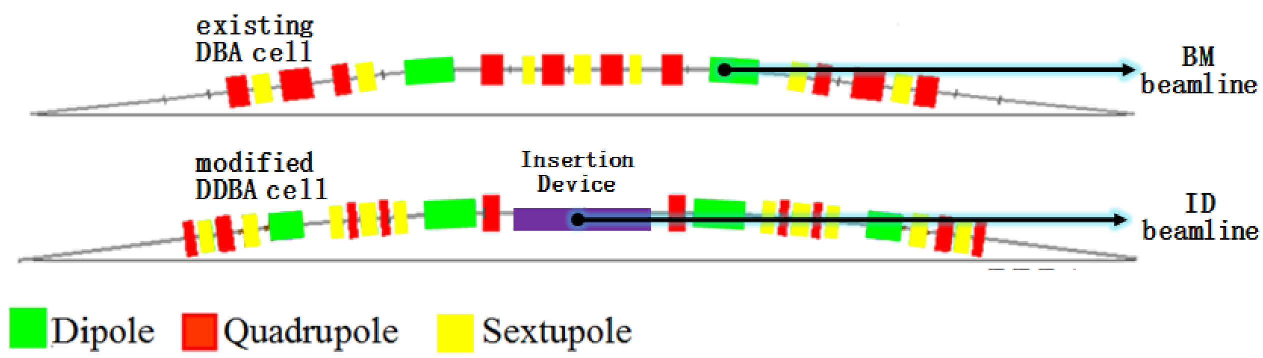

Figure 1: Schematic of old DBA and new DDBA cells.

the whole assembly. PLCs were employed to monitor temperatures at selected points and to control the numerous heater elements. One of the design constraints was as follows: if any temperatures at the sample points exceeded the permitted differences to other sample points, then an exception state would be triggered in the PLC state-machine. This pauses any temperature ramp (up or down) and holds the temperature stable until equilibrium is resumed. It was crucial to avoid simply switching off the heaters, which would result in uncontrolled cool down.

For the monitoring and control of deployed vacuum components, VME IOCs were replaced with diskless Linux servers and remote I/O.

Diagnostics

The DDBA cell included 8 Electron Beam Position Monitors (EBPMs), as compared to 7 in the other cells in the storage ring. The extra EBPM control system was installed and integrated into software in advance of the DDBA shutdown, but only enabled once the new hardware was installed. The two operational pinholes proved to be adequate for vertical emittance measurements and corrections, avoiding having to integrate the third pinhole, currently available for testing, into the production infrastructure.

Insertion Devices (IDs)

The original control system for the cell 2 ID occupied two racks.The additional hardware in the new cell placed constraints on the rack space available; the ID control system was re-engineered into one rack and upgraded to our preferred Delta Tau Brick type motion controller.

The ID to be installed in the new straight section and its control system were not installed during the DDBA shutdown, but was successfully installed and commissioned in a subsequent shutdown.

Girder Alignment

The DLS storage ring girders are aligned using a motion system consisting of five electromechanical actuators. The DBA cells are implemented on three girders with a total of 15 axes, the updated DDBA cell uses only two girders (shown in Fig. 2) with a total of 10 axes. The DBA girder actuators have extended travel whose limits exceed the safe displacement of the inter-girder vacuum bellows. The redesigned girder alignment system was implemented with a safe range of travel, negating the need for a protection system.

HIGH LEVEL APPLICATIONS

Accelerator Model

The design of the new lattice was carried out by the DLS Accelerator Physics group, and so the accelerator model was in place before the control system development started [2]. For testing high-level applications before commissioning, a virtual accelerator was developed based on that originally developed for DLS commissioning and updated for use at NSLS-II [3].

Global Software Systems

A number of feedback and feedforward systems operate on the DLS storage ring. For each of these, an updated scheme was established using the new accelerator model. This scheme was then implemented in software.

The only change required for RF feedback was to use all the new corrector magnets as input to the feedback. The most effective scheme for tune feedback did not use any of the new quadrupoles, and so the cell 2 quadrupoles were removed from the feedback scheme.

For both slow and fast orbit feedback systems, new functionality was developed to allow any BPM or corrector magnet to be removed from the system to allow flexibility in use. Slow orbit feedback can use all BPMs and all correctors, but two factors complicate the use of fast orbit feedback: some of the new vacuum vessel is made from copper rather than stainless steel; and some of the new corrector magnets are of a different design to the rest in the ring.

The previous vertical emittance feedback algorithm proved not to adapt to the new lattice. A more sophisticated algorithm was adopted using the changed skew quadrupoles present in the new lattice.

The core operation of the Topup software was not changed by the DDBA upgrade. A number of new safety interlocks

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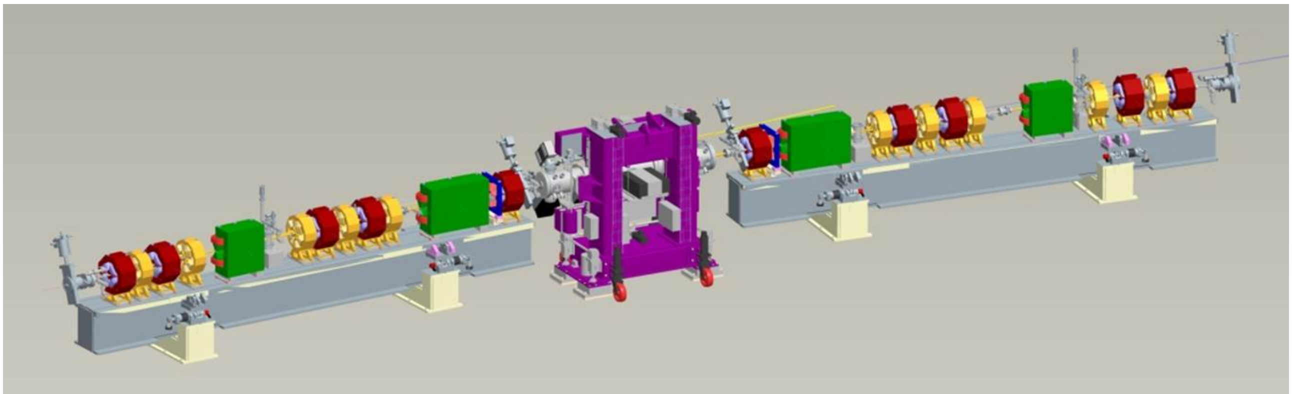

Figure 2: Diagram of the new DDBA cell, showing the two-girder design. Bending magnets are shown in green, quadrupoles in red and sextupoles in yellow.

were added and existing interlocks updated. The fast LOCO algorithm was also updated.

PLANNING

The Control Systems (CS) team reported into the wider project team on a monthly basis and also worked alongside the project planner to ensure that timescale commitments were sensible and achievable. The CS team also held regular internal meetings to ensure that all of the developments for each of the controls sub-systems were on-track for deployment in the eight-week shutdown. Individual members of the CS team took responsibility to liaise with their customer technical areas (such as vacuum, power supplies, etc.) to make sure that all changes were captured and resolved. The members of the CS team were required to work alongside colleagues from other technical areas as well as the mechanical installation team in a relatively small working area; to ensure overall progress of the project it was important that members of the team worked flexibility with a high level of cooperation. The level of planning and reporting worked well and the interdisciplinary cooperation meant that the control systems were implemented ahead of schedule, allowing the physics commissioning to start early.

INSTALLATION AND COMMISSIONING

Installation and commissioning of the new sector of the storage ring was carried out during an extended eight-week shutdown in October and November 2016. This shutdown was precisely scheduled, with the first six weeks allowed for installation and commissioning of components, and two weeks for electron beam commissioning [4]. To minimise the shutdown length, existing cabling was rerouted in advance and the space used to lay the new cables before the shutdown began [5].

There were few deviations from the installation plan and the storage ring was successfully commissioned during the scheduled shutdown.

CONCLUSIONS

The DLS DDBA upgrade was successfully carried out within the scheduled eight-week shutdown. The first six weeks were used for installation and commissioning of hardware, and during the final two weeks the electron beam was commissioned successfully, with a rapid return to standard operating conditions for users.

Due to the short period available for installation and commissioning, significant work was put into advance preparation: specifications were drawn up carefully; diagnostics hardware was installed in advance where possible; all hardware was tested in advance where possible; and high-level applications were tested against a virtual accelerator. These measures were intended to mitigate the risks associated with carrying out a complex process on a tight schedule. Since the commissioning progressed smoothly and finished slightly ahead of schedule, it was concluded that the preparatory measures taken were appropriate.

REFERENCES

[1] R.P. Walker *et al.*, "The Double-Double Bend Achromat (DDBA) lattice modification for the Diamond Storage Ring", in *Proc. IPAC '14*, Dresden, Germany, Jun. 2014, pp. 331–333.

[2] R. Bartolini *et al.*, "The DDBA cell upgrade at Diamond: from design to commissioning", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper WEPAB092.

[3] G. Shen, L. Yang, and Y. Li, "Virtual accelerator at NSLS-II project", *ICALEPCS'13*, San Francisco, CA, USA, Oct. 2013, pp. 471–474.

[4] I.P.S. Martin *et al.*, "Electron beam commissioning of the DDBA modification to the Diamond Storage Ring", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper WEPAB095.

[5] A. Thomson *et al.*, "Optimisation of electrical and instrumentation design for the Diamond Light Source DDBA upgrade", presented at IPAC'17, Copenhagen, Denmark, May 2017, paper MOPAB133.