CONTROL SYSTEM CHALLENGES FROM AN UPGRADE TO THE DIAMOND LIGHT SOURCE STORAGE RING

M. T. Heron, A. Rose, Presented on behalf of the DDBA control and instrumentation team,
Diamond Light Source, Oxfordshire, UK.

Abstract

In 2016 Diamond Light Source will replace one double bend achromatic cell of the storage ring (SR) with two double bend achromatic cells in the same longitudinal space. This will create an additional straight section for an insertion device (ID), thereby converting a bending magnet source point into an ID source point. Installation of the two new cells and recommissioning of the SR will take place in an eight week shutdown, with an expectation that post-shutdown operation will resume with a level of performance comparable to that pre-installation. The additional components in the two new cells necessitate a substantial reworking of the interface layer of control system, together with changes to all applications which are dependent on the physics parameters of the storage ring. This paper will describe how the control system aspects of this project will be managed.

INTRODUCTION

Diamond Light Source is part way through a project to replace one of the standard Double Bend Achromat (DBA) cells of the 561 metre circumference electron storage ring with a new design consisting two DBA cells and a straight section for an insertion device[1]. This arrangement of the two DBA cells has been termed the "Double-Double Bend Achromat" (DDBA) cell. The new insertion device associated with the DDBA cell will service a new photon beamline which otherwise would have had a bending magnet as its source.

The project management aspects of the DDBA project, from a control and instrumentation point of view, are of relevance to future projects at Diamond and other light sources. In the case of Diamond there are presently accelerator physics studies exploring whether a second DDBA can been installed in 2018, together with a conceptual design study considering how the whole storage ring could be rebuilt with a more modern lattice design to reduce the natural emittance. For other light sources, a number of facilities have plans to rebuild their storage rings with more modern lattice designs, again to reduce the natural emittance. As operational facilities, all these projects face the same challenge as the DDBA project in how to make such an invasive change to an operational facility while minimising the impact on user time and maintaining operational performance.

DDBA PROJECT

The existing DBA cell consists of two dipoles and ten quadrupole and seven sextupole magnets to bend and focus the electron beam, which are mounted on three girders. With the DDBA design, each half of the DDBA cell is mounted on one girder including five quadrupoles, five sextupoles and the two dipole magnets. Between the two girders is a new straight section that is used to house the new insertion device, as shown in Fig 1.

To fit a DDBA cell into the longitudinal space of a standard DBA cell necessitates higher field gradient magnets, and so requires smaller apertures. It also necessitates a greater number of magnets, including the addition of trim windings on the dipoles, to enable the existing dipole supply to be used for the main ampere turns and to be able to match the integrated field to that of the standard dipoles. While there are adequate numbers of corrector magnets for orbit correction on the sextupoles, a portion are located over copper vessels, which would significantly impact their dynamic performance in the global Fast Orbit Feedback (FOFB). This is addressed through additional separate correctors over stainless steel portions of the vacuum vessel. The ratings of the new quadrupoles are similar to the old, but the new sextupoles have lower impedance, so in both cases the existing power supplies can be used, albeit with a lower operating voltage for the sextupoles. There is one additional beam position monitor, hence one additional Libera Electron. For the vacuum vessel the use of lumped NEG pumps means fewer ion pumps, but a comparable number of vacuum gauges and additional vacuum valves. For vessel thermal protection there are comparable additional thermal monitors, thermal interlocks and water flows but in different locations. These differences in instrumentation are summarised in Table 1.

ELECTRICAL AND INSTRUMENTATION

From Table 1, the numbers of each component type in the DDBA cell are not significantly different from a standard DBA cell. However, for the majority of electrical circuits it was concluded that it would be better (quicker and operationally more reliable) if new cables were installed to connect the girder back to the instrumentation located outside the ring in the Control Instrumentation Area (CIA). This largely came about because one of the three cable penetrations would not be available after the changes, meaning that a third of the cables would need rerouting, and it was not evident there was sufficient cable length to reassign cables to their new locations on the DDBA cell. Despite the small overall change in numbers of components to control, the new instrumentation necessitated additional racks, which exceed the capacity of the CIA and so necessitate it being extended.

ISBN 978-3-95450-148-9

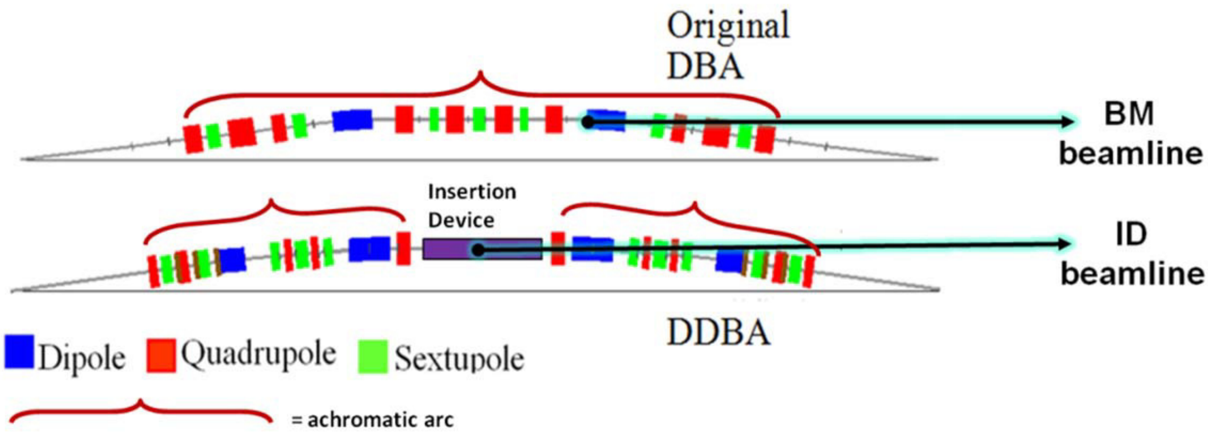

Figure 1: Changes from a DBA to DDBA cell.

For reasons outlined under the section on Project Management, components on the new girders will be pre-cabled to termination boxes and the rack-to-girder cables terminated with plugs to have a single interface point for each girder, thereby facilitating the installation, termination and testing of cables before the installation shutdown.

Table 1: DBA and DDBA, Number of Components

Components	DBA Cell	DDBA Cell
Dipoles (Main, Trim)	2,0	4,4
Quadrupoles	10	10
Sextupoles	7	10
Corrector Magnets on Sextupoles (H, V, Skew Quad)	7,7,4	10,10,4
Separate Corrector Magnets (H, V)	0	2,2
Beam Position Monitors	7	8
Vacuum Ion Pumps	18	7
Vacuum Gauges	7	11
Vacuum Valves	4	7
Vessel Temperatures	42	49
Vessel Temperature Interlocks	12	14
Vessel Water Flow Interlocks	16	14

CONTROL SYSTEM DEVELOPMENTS

At Diamond the EPICS based control system[2] is partitioned by geographical location and by technical system. Hence there are separate IOCs for each of the technical subsystems associated with a cell. IOCs for MPS, Corrector Power Supplies, Diagnostics, Quadrupoles and Sextupoles and Vacuum all require significant amounts of development. For each of these, versions of these IOCs are also being built with soft records to enable simulation of actual Process Variables (PVs) without the hardware, thereby enabling development and testing of overall summary views and global applications, such as sequencing start-up and shutdown of systems.

Protection of equipment is accomplished by standard solutions based on PLCs. For vacuum protection an additional vacuum valve control crate will be added to control the new valves and manage the interlocks to protect them and the ion pumps. For vessel protection a new PLC solution has been designed, where all temperatures that provide interlocks are hardwired back to the PLCs located in the CIA, while temperatures used for monitoring only are connected using remote analogue input modules. This differentiation comes from evidence of long term radiation damage to electronics located in the vault.

Diamond uses a number of the high-level applications, including Matlab Middle Layer, LOCO, and various bespoke applications for routine operation. In addition there is extensive use made of Matlab scripts for various physics studies. The scripts are large, uncontrolled and maintained by the user, so responsibility of updating them sits with the user. For the other applications, these are being updated for the new lattice configuration during late 2015 and early 2016. To enable a degree of early testing a Virtual Accelerator (VA) has already been built with the new lattice to present the same PV interface as the real machine, but on a different port. This will be used to test the applications prior to the machine becoming available. However, final testing will only be possible as part of commissioning with beam.

Routine operation of Diamond runs seven global real-time feedback and feedforward processes[3] to control beam position, vertical beam size and tune. All of these use model base information and, with the exception of the FOFB, run relatively slowly, i.e. sub one second sample rate, and communicate over EPICS PVs. They will be updated and tested, as much as possible, against the VA and soft IOC version of the new IOCs. Nevertheless, final testing will only be possible in installation shutdown and as part of commissioning with beam. For FOFB, the additional BPM was added to the low latency FOFB

ISBN 978-3-95450-148-9

Figure 2: Temporary cable installation.

network in early 2015, and the addition PSUs will be added in early 2016, but again final testing will only be possible in installation shutdown and as part of commissioning with beam. The TMBF should have limited lattice dependence but will need recommissioning.

PROJECT MANAGEMENT

The DDBA project plan is divided into two sections: Phase 1 covers work up until the installation shutdown and Phase 2 the installation shutdown. The critical path of the former was determined by the lead times for the design and manufacturer of magnets and vessels. This provides adequate time to build new control racks and implement the control system software changes. However in the initial planning of Phase 2, the installation shutdown, the critical path of fourteen weeks was dominated by the time to remove and re-install the electrical cables and recommissioning systems. A shutdown of this length was deemed operationally unacceptable, so options to shorten the shutdown were explored. The chosen solution was to install and terminate the new cables before the shutdown and to have a single termination panel for all cables on each of the new girders. This would allow girders cabling and rack-to-girder cables to be pretested and pluggable, to minimise shutdown cabling time. However, to install the new cables necessitated clearing the cable trenches of the old cables and this required the existing DBA girders be re-cabled back to the instrumentation racks on temporary cables, see Fig. 2. This process of switching to temporary cable could only happen during shutdowns and so was managed as part of Phase 1 of the project planning taking place during 2014 to 2016.

STATUS AS OF AUTUMN 2015.

As of autumn 2015 the major contracts are well underway for magnets and vessels, with girders already delivered and a new temperature stabilised alignment room constructed. The enabling work to install and switch to temporary cable took place in the first half of 2015 with no impact on operations. Then the original cables were removed, and in the summer 2015 shutdown the dipole circuit was rerouted. Designs for new instrumentation systems are being reviewed, and new instrumentation racks are being constructed. The additional BPM was installed and added to the FOFB network. The extension to the CIA was completed in early 2015.

The VA has been built, and work is now commencing on updating the physics applications. This is in line with the Phase 1 plan. The planned installation and commissioning shutdown is set for August and September 2016. The Phase 2 plan has been detailed, and it is clear that installation and subsequent recommissioning of the storage ring will be challenging. Given the established user community it remains critical that routine operation is re-established as planned, and in addition that the user community are briefed on the expected level of operational performance (beam properties and reliability) on start-up, to help manage their expectations.

CONCLUSION

In terms of control systems, replacing one cell of storage ring is not as challenging as replacing the whole ring. However, it still poses a risk to an established operational facility, both in terms of the time off-the-air and re-establishing routine operations at a level of performance and reliability expected by an established user community. From the DDBA project it has become evident that the mechanical engineering aspects lend themselves to being prepared off-line, and it is the electrical and control aspects that naturally dominate the installation and recommissioning time. However, we have shown that through upfront enabling work, the time and risks associated with control system related tasks during the upgrade can be minimised.

ISBN 978-3-95450-148-9

REFERENCES

[1] R.P. Walker et al., "The Double-Double Bend Achromat (DDBA) Lattice Modification for the Diamond Storage Ring", IPAC'14, Dresden.

[2] M.T. Heron, et al., "The Diamond Light Source Control System", EPAC06, Edinburgh.

[3] M.T. Heron, et al., Feed-forward and Feedback Schemes Applied to The Diamond light Source Storage Ring, IPAC14, Dresden.

ISBN 978-3-95450-148-9