THE DOUBLE-DOUBLE BEND ACHROMAT (DDBA) LATTICE MODIFICATION FOR THE DIAMOND STORAGE RING

R.P. Walker, M. Apollonio, C.P. Bailey, M.P. Cox, R.T. Fielder, N.P. Hammond, M.T. Heron, J. Kay, I.P.S. Martin, S.P. Mhaskar, G. Rehm, E.C.M. Rial, B. Singh, V. Smaluk, A. Thomson,
Diamond Light Source, Oxfordshire, UK
R. Bartolini, Diamond Light Source, Oxfordshire, UK; JAI, Oxford UK
T. Pulampong, JAI, Oxford, UK

Abstract

We present an overview of the status of the DDBA project, the various accelerator physics and engineering studies that have been carried out, and plans for the implementation of one or two DDBA cells in Diamond.

INTRODUCTION

The concept of converting individual cells of the Diamond Double Bend Achromat (DBA) lattice into a modified 4-bend achromat with a new straight section for insertion devices (IDs) in the middle of the arc, grew out of earlier studies of low emittance multi-bend achromat lattices [1], and was motivated by the need for additional insertion device (ID) straight sections, since all of the 22 ID straight sections in the Diamond storage ring are either occupied or have been allocated to future beamlines. Such a modification effectively replaces a DBA cell with two new DBA cells, as shown in Fig. 1, hence the term Double-DBA or DDBA has come to be used for the project. Since the tangent point for bending magnet beamlines lies close to the start of the second dipole in the DBA lattice, this allows unused bending magnet exit ports and spaces on the experimental hall to be used for higher performance ID beamlines.

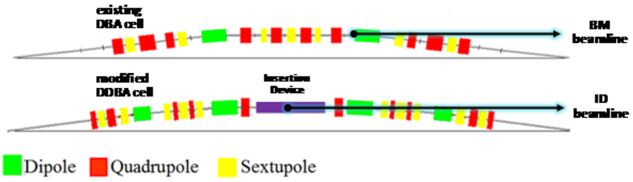

Figure 1: Schematic diagram of the existing DBA cell and the modified DDBA cell.

Initial design work on DDBA was presented in [2]. In this report we give an overview of the project and its current status, with more specific information on accelerator physics, engineering and magnets being presented in companion papers [3,4,5].

PROJECT EVOLUTION AND DESIGN CHOICES

Motivation

The DDBA project is driven by the requirement for an additional ID straight section for a funded Phase III beamline VMX ("A versatile micro-focus and in-situ diffraction facility for macromolecular crystallography"). VMX involves modification of an existing insertion device beamline (I02) as well as the construction of a new beamline. With no further straight sections available, the initial proposal for the new beamline was to use a short ex-vacuum ID in the same straight section as the existing I02 in-vacuum undulator, but at a small angle to it. Implementing a DDBA cell however provides the possibility for the new beamline to have a full-length in-vacuum undulator as the source, with significantly increased brightness. An additional benefit is that the new beamline can now be built independently of the existing I02 beamline which significantly reduces the amount of down-time needed.

Lattice Design

The initial idea was that single DDBA cells could be installed prior to a possible later replacement of all 24 cells. However, the timescales demanded by the requirement for a new ID straight for VMX were incompatible with optimization of essentially two (or more) different machines, and so the one cell case had to take priority. The two cell case has also received considerable attention but is currently not as well advanced as that of one cell.

The first acceptable lattice was arrived at without constraint on the magnet lengths, resulting in two types of quadrupole and two types of sextuple magnet. Later this was rationalised to single types of both quadrupole and sextupole in order to reduce manufacturing costs. These changes initially cause a deterioration of the calculated dynamic aperture and Touschek lifetime, however painstaking optimization has now almost recovered the earlier results. The currently predicted lifetime (dominated by Touschek scattering) is 17.6 h (300 mA, 686 bunches, 1 % coupling), compared to 21.1 h for the existing machine which is deemed acceptable.

Considerable effort has been expended also on trying to develop optics with low momentum compaction so as to be able to continue to offer this "low-alpha" mode to users [6]. So far it has not proved possible to obtain a dynamic aperture (DA) as large as that achieved with the current lattice. With an on-momentum DA of only +9.4/-7.2 mm mm at the injection point (IP), the injection efficiency from 6D tracking for the ideal lattice is only ~2 %, with the current centre of the injected beam at -8.3 mm with respect to the stored beam at the IP, and with a horizontal injected beam size of 0.7 mm rms. The solution under study is to reduce the oscillation amplitude by bringing both injected and stored beams closer to the

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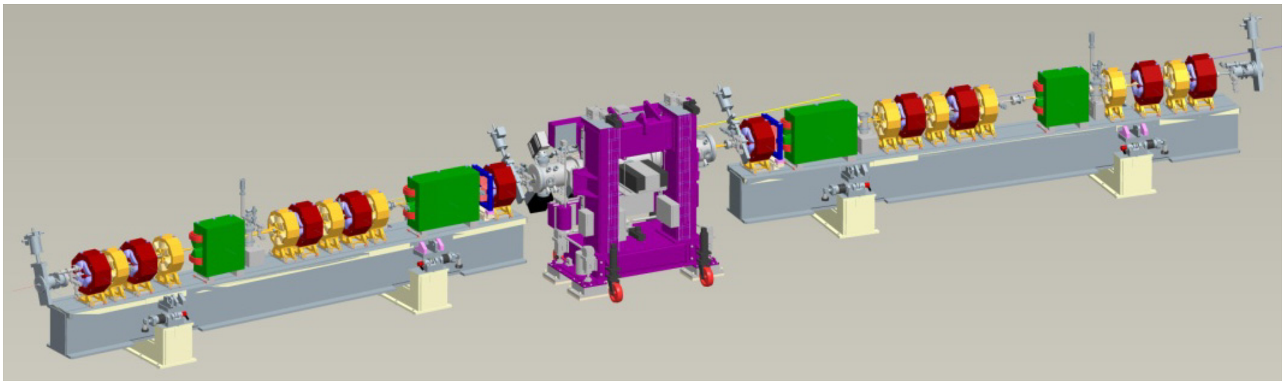

Figure 2: Engineering model for one DDBA cell with a standard Diamond in-vacuum undulator in the newly created straight section.

septum. To achieve this without increasing the stored beam bump, the septum will be moved closer to the circulating beam. Our current measurements suggest that the injected beam offset can be reduced to 6.8 mm, whilst still leaving 0.8 mm contingency, resulting in a calculated injection efficiency of ~20%, comparable to the present situation. In low-alpha mode injection efficiency is predominantly limited by particle losses in the longitudinal plane due to the relatively long length of the injected bunch. The septum move is currently planned for the August 2014 shutdown.

Magnets and Power Supplies

It was decided to proceed with discrete magnets since the lattice design allowed this possibility and the available resources and required timescales were not compatible with the more complex "integrated magnet" approach of MAX-IV. Permanent magnet dipoles were considered, and while attractive, were rejected for the same reasons.In order to achieve the required field strengths narrow pole gaps are required. As this is not a new storage ring, Beam Stay Clear apertures had to be defined in relation to the present limiting fixed apertures defined by the horizontal collimators, and the narrow gap vessel in one of the ID straights. This led to the choice of an elliptical vacuum vessel with nominal internal dimensions of 27 mm (H) x 18.4 mm (V), with 1 mm wall thickness. Allowing sufficient clearance between vessel and magnet poles led to a dipole magnet gap of 30 mm (at the beam axis) and inscribed radius of 15 mm for quadrupoles and sextupoles.

The C-shaped horizontally defocusing dipoles will be of two different lengths, with 0.8 T field and 14.4 T/m gradient. In order to reduce the overall length, the magnets will use the "extended pole" concept [7] so that the pole tips are longer than the yoke. In the present case, because of the narrow gap, the whole length of the pole tip must be removable so that the coils can be installed. The quadrupoles are designed to reach a maximum gradient of 70 T/m, and the sextupoles a second derivative (d^2B_y/dx^2) of 2000 T/m^2. Dipoles and quadrupoles will be constructed of solid steel, while the sextupoles will be laminated in order to achieve the required dynamic performance for the dipole correction fields. Additional short horizontal and vertical correctors are located on either side of the ID (shown blue in Fig. 2).

Another design choice has been to make use of existing power supplies, and existing power supply types, wherever possible. The dipoles will have two coils, one powered in series with the existing dipole circuit (1353.5 A at 3 GeV), the other by a new 200 A supply, one for each magnet. The quadrupoles and sextupoles will be powered by the existing 200 A and 100 A supplies respectively. The sextupoles will contain windings for horizontal and vertical correctors and skew-quadrupole fields as in the existing magnets, powered by existing 5A supplies.

Vacuum Vessels and Pumping

The vacuum vessels were originally conceived to be a combination of copper, in the regions of high heat load i.e. in the dipoles, and stainless steel elsewhere, particularly in the sextupoles to provide the required dynamic correction field capability. Detailed FEA of the vacuum vessels has since resulted in the copper vessels being extended through sextupoles 3, 6 and 9 which follow dipoles 1, 3 and 4. In addition, a copper vessel is also required in the short corrector (and quadrupole) following dipole 2. Calculations confirm that dynamic orbit correction can be adequately performed using only 6 correctors in the cell, with 8 being available for static/slow correction.

Given the small aperture vacuum chambers, it was initially proposed to employ NEG coating. However, a later realisation of the R&D effort required, and the timescales and risk involved, forced a re-think and a careful investigation of alternative possibilities was made. With the introduction of 7 NEG cartridge pumps, together with ion pumps under the 3 crotch vessels, acceptable vacuum conditions were obtained from the vacuum model, which has been validated against the initial conditioning of Diamond. Dynamic vacuum levels are of course not as good as achievable with NEG coating, and also slightly worse than in the existing ring – approximately 3 times worse for a given conditioning dose. Acceptable vacuum levels of 3.10^{-9} mbar can however still be reached in a reasonable conditioning time of 200 Ah. The fact that this is only one cell of a 24 cell machine means that the influence on machine operation will be minimal. The insertion device in the middle of the new DDBA straight section will not be installed until the following shutdown giving further conditioning time to reduce local Gas Bremsstrahlung levels before the new beamline becomes operational.

Beam Diagnostics

The DDBA cell will have a total of 8 Electron Beam Position Monitors (EBPMs) as opposed to the 7 EBPMs in the standard DBA cell. Of the 8 EBPMs, two will be the original ‘primary EBPMs’ (facing the insertion devices and mounted directly to the floor with physical reference pillars) adjacent to the unmodified straight sections. Two further EBPMs will be the ‘new primary EBPMs’ with a smaller racetrack cross-section directly upstream and downstream of the new ID, while there will be a further four EBPMs on the elliptical cross-section vessels located between the DDBA magnets.

All except two EBPMs will feature double or single bellows/spring finger units to decouple them from any mechanical motion of the vacuum chamber as far as possible, and be equipped with optical position encoders which reference them to a nearby magnet or the floor.

The button feedthroughs for the new EBPM blocks have been designed with significantly smaller diameter (6 mm instead of the 10.3 mm in all other locations) to achieve a good compromise between sensitivity and wake losses.

Control System

The Control System for the DDBA cell will largely rework the existing solutions based on VME based EPICS IOCs for the interface to the technical systems. For vacuum, front-ends and insertion devices new control systems will be realised based on current practice of using 1U PCs and Linux for EPICS IOCs, the main advantage being a reduction in the rack space required.

An extension of the Control & Instrumentation Area will be required to accommodate the greater number of racks needed for the DDBA cell.

STATUS AND PLANS

Approval has been given for one cell of DDBA to be installed in the ring to accommodate a new ID for the VMX beamline. The beamline timescales determine those of the DDBA project, and it has now been decided that the shutdown for the installation of one cell of DDBA will begin on August 5th 2016.

The current status is that a contract has just been placed for the magnets, and a call for tenders for vacuum vessels is imminent. The next priority is to complete the design of the girders and issue a call for tenders in July.

In order to minimise the shutdown period required, two new fully assembled girders will be prepared for the upstream and downstream parts of the DDBA cell. In order to minimise the amount of cabling works needed during the main shutdown, the following procedure has been adopted, with works already commenced during the March 2014 shutdown:

- temporary cables will be installed for the existing DBA cell via the personnel labyrinth,
- the DBA cell will be connected up progressively to the temporary cables,
- the existing cables will be removed leaving the cable ducts and trays empty,
- new cables for the DDBA cell will be installed and terminated,
- during the shutdown for DDBA installation, the girders will be connected up to the new cables and commissioned. The temporary cables will remain in position for some time as part of a recovery plan in case DDBA has to be removed and the DBA cell re-installed.

With this pre-installation of the cabling, as well as other preparatory works, the shutdown can be limited to an acceptable 8 weeks.

A second cell of DDBA is being considered for the Dual Imaging And Diffraction (DIAD) beamline which was recently added to the Phase III programme. It was originally proposed to build DIAD on a 3 T Superbend [8], the new plan however involves an in-vacuum undulator in a new straight created by implementing a second DDBA cell. The provisional plan is that the second cell will be implemented two years later than the first in 2018.

CONCLUSION

The DDBA project is proceeding and procurement is underway, targeting an installation of one cell starting in August 2016.

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