ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW077

IMPACT OF THE DIAD WIGGLER AND 'MISSING-SEXTUPOLE' OPTICS ON THE DIAMOND STORAGE RING

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Abstract

In order to generate space for a short, out-of-vacuum multipole wiggler for the DIAD beamline, a single sextupole was removed from one of the DBA arcs in the Diamond Storage Ring during June 2018. The removal of this sextupole presented a number of challenges to the operation of the storage ring, requiring a re-optimisation of the remaining sextupole strengths [1], a change in tune-point and modification of the orbit and coupling correction schemes. In this paper we describe the implementation of these changes, and provide an assessment of the impact that the installed wiggler has made on the storage ring parameters.

INTRODUCTION

Since the beginning of user operations in January 2007, the number of operating beamlines in the Diamond storage ring has increased from 7 to 36, consisting of a range of bending magnet, undulator and multipole wiggler sources. In order to accommodate this increase, a number of modifications have had to be made to the storage ring, such as canting of insertion devices (IDs) in standard straight sections, installation of additional quadrupoles to create double mini-beta optics in the long straights [2], and replacement of an entire double bend achromat (DBA) cell with a Double-DBA arc [3, 4].

The Dual Imaging and Diffraction (DIAD) beamline is the most recent to be installed. This beamline operates at photon energies between 7 and 38 keV, with a spatial resolution of less than 1 μm. Given the clear desire to maximise flux density, an ID source was preferred. However, since the straight sections in the storage ring are now fully occupied, space had to be created for this ID within a DBA cell by removing one of the chromatic defocussing sextupoles. Before approval of this project, extensive studies were carried out to find the best mitigation strategy for the loss of the magnet. This work identified that injection efficiency and lifetime could be maintained close to the existing values by doubling the strength of the partner defocussing sextupole within the arc, and by making small adjustments to the betatron tunes and remaining harmonic sextupole families [1].

The DIAD wiggler is a fixed-gap hybrid device of period 116 mm, peak field 1.54 T and 0.7 m total length, as shown in Fig. 1. It is permanently in position, but can be removed mechanically if required by means of a screw-thread and horizontal sliders. In this paper we present the machine studies carried out in preparation for the lattice modification, re-commissioning of the storage ring following the replacement of the DIAD-cell girder, and the impact that the DIAD wiggler has had on the operational performance.

Figure 1: DIAD wiggler installed between two quadrupole magnets in the centre of a DBA cell.

PREPARATORY STUDIES

A summary of the changes required to accommodate the DIAD wiggler is given in Fig. 3. Aside from the removal of the sextupole, the installation also resulted in the removal of one pair of horizontal and vertical correctors and one skew quadrupole magnet, and for two BPMs and a further pair of correctors to be disabled from the orbit feedbacks.

Sextupole Tests

The work summarised in [1] identified that increasing the strength of the partner defocussing sextupole is an effective way of restoring the dynamic aperture after the modification. In standard optics this is possible within the design operating range, however, for low alpha operation doubling the strength requires running the magnet deep into saturation and replacing the 100 A power supply with a 200 A one. Tests conducted on a spare magnet demonstrated this was possible, with thermal equilibrium reached for 75 % cooling water flow rate and a temperature increase of 14.9°C. The calibration curve for the magnet is shown in Fig. 2.

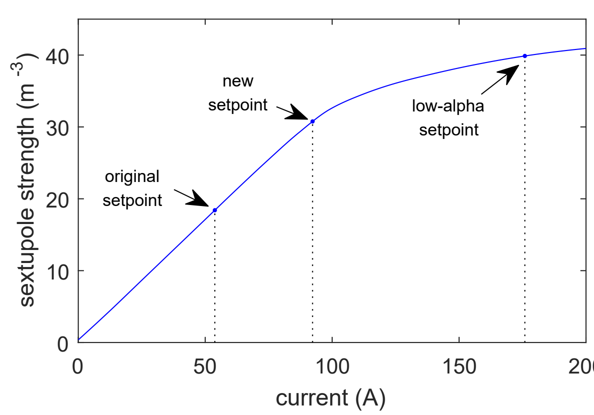

Figure 2: Strength as a function of current for the remaining defocussing sextupole magnet.

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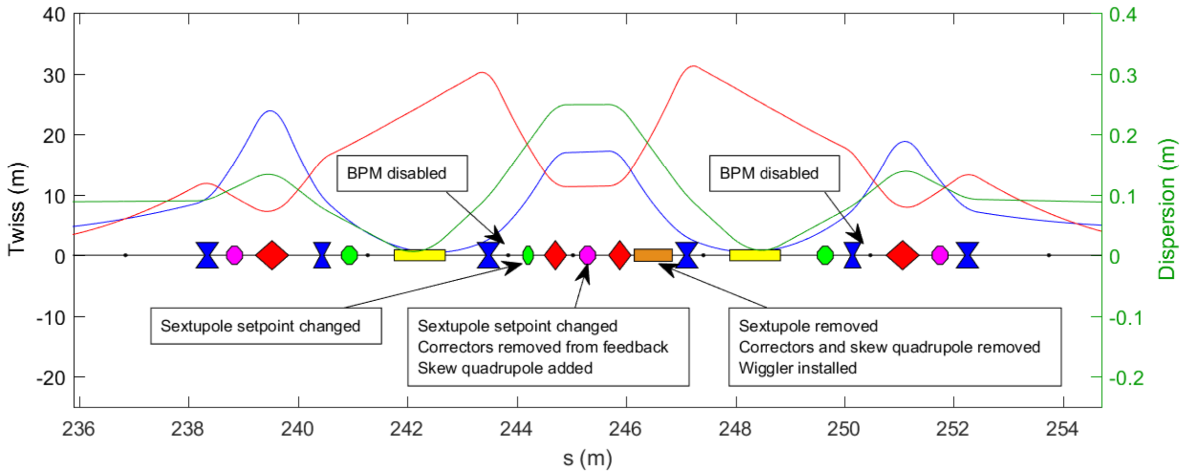

Figure 3: Summary of changes required in the local DBA cell to accommodate the DIAD wiggler.

Orbit Correction

The sextupole magnet replaced by the DIAD wiggler also contained horizontal corrector, vertical corrector and skew quadrupole windings, resulting in the loss of these functions at that location. The focussing chromatic sextupole immediately upstream of the wiggler is also used for horizontal and vertical correction, but given its proximity to the wiggler and lack of intervening BPMs the decision was taken to leave these correctors at set-point but remove them from the orbit feedback. This leaves a total of 5 horizontal and 5 vertical correctors within the cell.

In principle, all 7 BPMs could continue to be used for orbit feedback. However, when run in this configuration the correctors are quickly driven to saturation due to a singularity that appears in the inverse response matrix. Given the two BPMs closest to the wiggler are required to stabilise the photon beam, it was decided to disable BPMs #3 and #6. This action removed the singularity and left the orbit feedback operating with 5 BPMs and 5 correctors in each plane and behaving regularly.

Coupling Control

The loss of a skew quadrupole within the arc was found to lead to a small but measurable increase in the minimum vertical emittance achievable. It remained straight-forward to correct to 2 pm.rad or below (well below the operating value of 8 pm.rad), but given the adjacent focussing chromatic sextupole already contained skew quadrupole coils, it was decided to simply move the relevant power supply across from one magnet to the other and maintain 4 skew quadrupoles per cell. Preliminary tests using a spare power supply demonstrated that with such a change, identical coupling control can be achieved in both cases.

COMMISSIONING RESULTS

To gain confidence in the operational performance before installation, the Diamond storage ring was run with the missing-sextupole configuration during user time from April 2018, with the actual girder swap taking place during the following shutdown (June 2018). The DIAD wiggler was then installed in position during November 2018.

Optics Commissioning

Although the missing-sextupole lattice can in principle be implemented without changing the linear optics, the new sextupole settings result in a substantial change to the detuning with amplitude and required the working point to be shifted from $[Q_x,Q_y]$ = [28.172,13.273] to [28.189,13.277]. These values are a compromise between maximising lifetime and maximising injection efficiency, and have been proven to be largely insensitive to ID gap and phase changes.

The new working point also required the horizontal chromaticity to be lowered from 2.0 to 1.7 to achieve the best lifetime and injection efficiency, with the vertical chromaticity left at 2.2 for single bunch instability reasons. In order to suppress resistive wall and vacuum-related instabilities, it is now necessary to use the transverse multi-bunch feedback (TMBF) in both planes during operations.

Once the girder-swap had been completed, updated set-points for the frozen corrector magnets upstream of the DIAD wiggler had to be found. These were optimised based on trying to minimise the electron beam displacement in the disabled BPMs #3 and #6. In future, these corrector settings could potentially be used by the beamline in order to control the photon beam pointing angle.

Wiggler Commissioning

Despite the fact that the DIAD wiggler is placed in a region of high dispersion, the change in emittance is relatively weak and the main impact is on the vertical tune point and beta beat [1]. These effects are summarised in Table 1 and Fig. 5 respectively, showing good agreement with theory. The vertical orbit distortion introduced by the wiggler is compensated by the ID trim dipoles, which bring the peak distortion down from 390 μm to below 30 μm.

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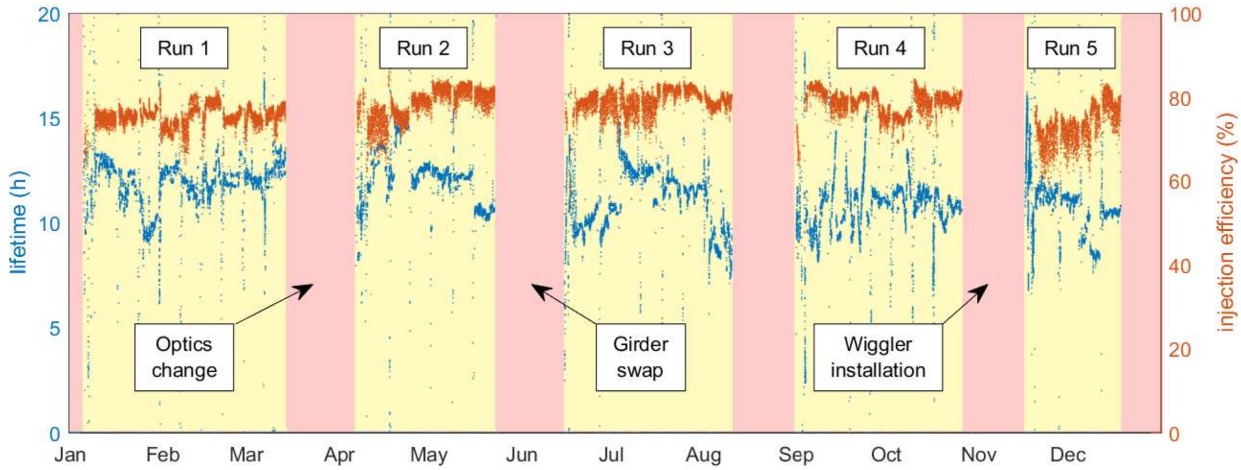

Figure 4: Lifetime and injection efficiency during 2018. Sustained drops in lifetime coincide with hybrid filling patterns (when bunch charge is higher and are therefore independent from the DIAD modifications), and periods of large variability occur during machine development days.

Table 1: Impact of DIAD Wiggler

Parameter	Theory	Measured
ΔQ_x	+0.0000	-0.0003
ΔQ_y	+0.0112	+0.0144
$\Delta \xi_x$	+0.00	-0.09
$\Delta \xi_y$	-0.02	+0.02
$\Delta \epsilon_x$	+0.036 nm.rad	+0.046 nm.rad
$\Delta \sigma_E$	-0.0001 %	+0.005 %

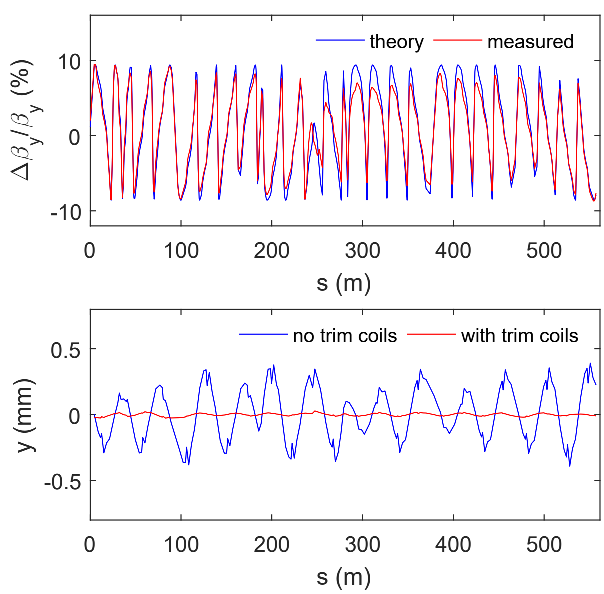

Figure 5: Vertical beta-beat (top) and orbit distortion (bottom) introduced by the DIAD wiggler.

OPERATIONAL PERFORMANCE

The lifetime and injection efficiency during 2018 are shown in Fig. 4. After implementation and optimisation of the missing-sextupole optics there was a small increase in injection efficiency, with some sensitivity to ID gap and phase changes still visible. Extended periods showing an increased variability and an overall reduction in injection efficiency were later found to be due to a mismatch between booster and storage ring RF phases.

The change in optics led to a drop in lifetime of around one hour, in line with expectations [1]. As with the injection efficiency, lifetime remains sensitive to the precise ID configuration, and significant drops in lifetime occur when operating with a hybrid filling pattern. This is due only to the increased charge per bunch in this mode, and is unrelated to the DIAD modifications.

In parallel with work on the standard missing-sextupole optics, a new 'low-alpha' lattice has been developed. This shows comparable performance to the original solution [5], with small degradations in both lifetime and injection efficiency. A slight lowering of the bursting thresholds had previously been observed after installation of the DDBA cell in 2016. The first user period with the new optics is scheduled for the end of May 2019.

CONCLUSIONS

The Diamond storage ring has been successfully operated in the missing sextupole optics for over one year, with the DIAD wiggler permanently in position for the last six months. No significant change in operational performance has been observed during this time, and reliability has been maintained.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the information received and support provided by members of the ID Group at Diamond, as well as the information on sextupole performance from Abolfazl Shahveh.

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REFERENCES

[1] B. Singh *et al.*, "Studies to Install a Multipole Wiggler by Removing a Chromatic Sextupole in the Diamond Storage Ring", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 3518–3521. doi:10.18429/JACoW-IPAC2016-THPMR050

[2] B. Singh, R. T. Fielder, I. P. S. Martin, G. Rehm, and R. Bartolini, "Implementation of Double Mini-beta Optics at the Diamond Light Source", in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastian, Spain, Sep. 2011, paper WEPC042, pp. 2103–2105.

[3] R. Bartolini *et al.*, "Double-double Bend Achromat Cell Upgrade at the Diamond Light Source: From Design to Commissioning", *Phys. Rev. Accel. Beams*, vol. 21, p. 050701, 2018.

[4] I.P.S. Martin *et al.*, "Characterization of the Double-double Bend Achromat Lattice Modification to the Diamond Light Source Storage Ring", *Phys. Rev. Accel. Beams*, vol. 21, p. 060701, 2018.

[5] I.P.S. Martin *et al.*, "Experience with Low-alpha Lattices at the Diamond Light Source", *Phys. Rev. ST Accel. Beams*, vol. 14, p. 040705, 2011.