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FEED-FORWARD AND FEEDBACK SCHEMES APPLIED TO THE DIAMOND LIGHT SOURCE STORAGE RING

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Abstract

Since initial operation for users in Jan 2007, Diamond Light Source has developed to support a suite of 24 experimental stations. These stations have resulted in the installation of 24 undulators and two superconducting wigglers in the storage ring. To preserve optics, tune and coupling with the operation of these devices has necessitated the implementation of a number of feed-forward and feedback schemes. The implementation and operation of these correction schemes will be described.

INTRODUCTION

Diamond Light Source [1] is a third-generation 3 GeV synchrotron light source based on a 24-cell double-bend achromatic lattice of 561 m circumference. The photon output is optimised for high brightness from undulators and high flux from multi-pole wigglers. It now operates for 5000 hours per year with 24 operational beamlines.

Where possible, sources of disturbance to the photon beam's performance are identified and removed at source; however to maintain the required photon beam properties a number of active correction schemes are required on the electron beam. Beam position stability is one of the key challenges of 3rd generation light sources both in maintaining submicron photon beams on samples but also in maintaining the optics of the machine. In the case of positional disturbances induced by insertion devices (IDs), coming from gap changes, these are largely corrected locally to the ID. Nevertheless there remains an ID-induced component that, along with other disturbances, necessitates active stabilization of the electron beam position.

Diamond operates in top-up mode in order to deliver near-constant photon flux and minimise heat-load-induced disturbances to beamline optics and machine components. However the top-up safety case dictates constraints on injection efficiency (> 50 % in normal optics) and lifetime (> 7 hrs) which are sensitive to the machine optics, and are again influenced by ID gap changes and general drifts in the machine.

To optimise photon beam brightness the vertical beam size is reduced by operating with a coupling of 0.3 %, which is sufficiently small that day-to-day drifts are significant.

To manage these disturbances a number of active correction schemes have been implemented. Reference [1] describes the physics of these corrections, while this paper concentrates on a summary of their realisation to give an overall picture, as shown in a conceptual form in Fig 1.

HARDWARE ENVIRONMENT

The feedback (FB) and feed-forward (FF) schemes, discussed below, operate at three distinct sample rates: Transverse Multi Bunch Feedback (TMBF) at 500 MHz, beam position FB at 10 kHz and the rest at 0.1 to 10 Hz. While TMBF and position FB each run on dedicated hardware the remaining systems are realised on EPICS IOCs. The communication is realised over the EPICS Channel Access protocol and the FF and FB processes are realised as either conventional EPICS IOCs using record processing or as Python IOCs [2] with processing implemented as a few hundred lines of Python code, meaning that they are resistant to bugs and easy to maintain. Most of the actuators are magnets controlled using a standard power supply unit (PSU) controller and EPICS interface. For some Quadrupole PSUs, the control system interface includes multiple FF or FB signals summed onto an operating set-point. To accommodate this each power supply controller makes provision for update from correction tables, calculated local to the PSU IOC, plus additional summing nodes which can point to a PV on another IOC that contains the correction value. The latter provides visibility of where changes are originating and facilitates adding, removing or updating the source without having to rebuild the PSU IOC.

Diamond has 26 installed IDs of a variety of types: in-vacuum undulators, out-of-vacuum APPLE-II helical undulators, permanent magnet wigglers and Superconducting Wigglers (SCW). All these IDs have an impact on the electron beam, and as a result we have implemented a number of feed-forward (FF) correction mechanisms based around 1D and 2D breakpoint tables. The software is implemented in a single EPICS genSub record that has a number of inputs for the control variables and a number of inputs to configure the internal behaviour of the tables.

FEED-FORWARD CORRECTION SCHEMES

Orbit Correction

Each ID is fitted with two pairs of corrector magnets for vertical and horizontal correction at either end of the magnet arrays. These correctors are used to correct orbit distortions that are a result of the field generated by the ID. The magnet set-point currents are controlled by the FF 1D/2D breakpoint table. For the in-vacuum undulators, the correction current is a function of the gap (1D). For the Helical undulators the correction current is a

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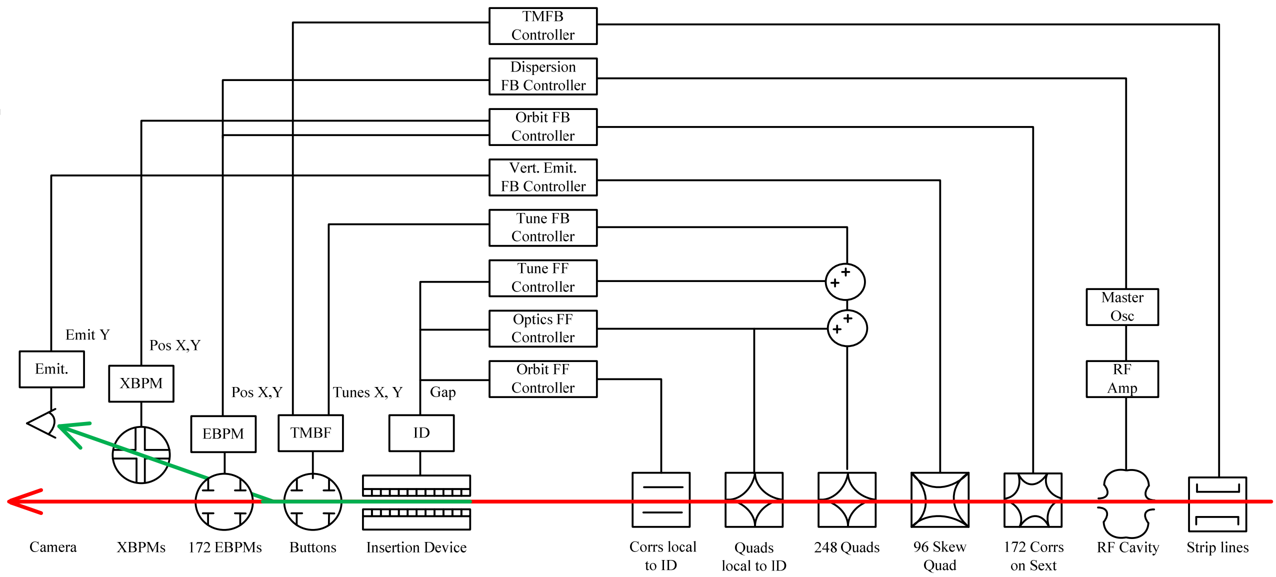

Figure 1: Conceptual view of the feedback (FB) and feed-forward (FF) correction schemes on the Diamond Storage Ring (Red is the electron beam and Green the photon beam).

function of the gap and the horizontal phase axis position (2D). For the SCWs the correction is a function of the calculated field (1D). This suppresses orbit disturbance to better than 10 μm, with the remaining disturbance being managed by the global position feedback.

Tune Correction

The two SCWs introduce a large tune shift [3], which is corrected with a FF scheme based on a 1D breakpoint table to generate corrections to the quadrupole triplets either side of the ID. The J09 ID is equipped with four horizontal phase axes allowing full polarisation control; this causes considerable tune shift and beta-beat in vertical or circular polarisation [4]. Given the extra degrees of freedom possible with this design, the number of allowable phase axis configurations is constrained to four and the correction scheme currently uses three 2D FF breakpoint tables, with the ability to switch between the tables based on the relative positions of the phase axes.

Optics Correction

For the I05 APPLE-II helical undulator fourteen shim wires are installed along the top and bottom of the length of the vacuum vessel [5]. These shim wires are used to compensate for linear and non-linear optics distortions based on ID gap and phase (2D). The SCWs and J09 ID [4] also introduce significant beta-beat, which is corrected using 1D and 2D FF tables acting on two families of global quadrupole magnets.

FEEDBACK CORRECTION SCHEMES

Orbit Correction

Global orbit feedback is required to compensate for residual ID disturbances and other disturbances. Position information from electron beam position monitors (EBPMs) is distributed using a low latency communication controller to each of 24 computation nodes which each calculate updates for one cell's worth of correctors. The feedback process uses a regularised version of the model inverse response matrix and an internal model controller together with some logic — for starting and stopping in a controlled way — and is realised on the AltiVec coprocessor on MVM5500 processor boards. This results in position stabilisation to less than 1.0 μm in X and 0.4 μm in Y up to a frequency of 100 Hz [6], and meets current operational requirements for beam stability.

X-ray photon beam position monitors (XBPMs) in each front end measure the position and direction of almost all the photon beams. Although the global orbit feedback stabilises the beam to within 10 % of vertical beam size there is still a residual slow movement seen on the photon beam; this is due to electrical movement of EBPMs, a small amount of floor movement and uncorrectable movement in bending magnets. This is corrected at around 10 Hz on a limited number of XBPMs by adjusting the target point for EBPM correction.

Vertical Emittance Correction

Vertical Emittance (VE) FB is required to compensate perturbations due to changes in ID gap, tune variation and long-term drifts [7]. A diagnostics IOC measures horizontal and vertical beam sizes from X-ray pinhole cameras. From these the emittances are extracted using the beta function values from the machine model and the dispersion values measured with IDs at typical gaps. The VE controller applies correction deltas to each of the 96 skew-quadrupoles. It is realised as a Python IOC, running at 5 Hz, and can effectively stabilise the VE at 8 pm rad during operational conditions.

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Tune Correction

Injection efficiency and lifetime of the Diamond Storage Ring drift with time and with changes to ID gaps and field [1]. Controlling the tunes is necessary for maintaining these parameters at appropriate values.

The TMBF [8] provides a robust tune measurement as EPICS PVs and by using the tune response matrix, it is possible to calculate current corrections for the relevant families of quadrupoles. Tune feedback runs at 1 Hz, applying 0.2 of the calculated correction in any one step. A Python IOC monitors the tune values and performs the feedback calculation, writing updates to summing nodes on the quadrupole power supply setpoints. These summing nodes make it easy to determine tune feedback's contribution to the individual magnet currents. If that contribution exceeds a certain limit, or if the tune measurements fall outside specified limits, the feedback loop will stop. Tune feedback has operated on the Diamond storage ring since early 2014 and typically maintains the tune to better than 10^{-4}.

Dispersion Correction

Dispersion Correction FB is used to minimize the effects of path length changes introduced by orbit FBs. The feedback process polls the Horizontal corrector magnet values, ΔI, at 0.1 Hz. The orbit response matrix R is used to convert this into effective position deviations. The dispersion response matrix D can then be used to determine the required change in RF frequency,

$$\Delta RF = \Delta I R D^{+},$$

where D^{+} is the pseudo-inverse of D.

The FB is not only applied slowly but is also restricted to making changes of 0.1 Hz to the Master Oscillator to minimize low frequency noise and prevent over-correction on spurious values. Only the horizontal dimension is required for accurate correction.

Transverse MultiBunch Correction

As more current is injected into the storage ring there is a tendency for the individual bunches to oscillate at the tune frequency (measured in 100s of kHz) in horizontal and vertical position [8]. The TMBF processor suppresses this tendency by measuring the horizontal and vertical position of every bunch (at 500 MHz, the machine RF frequency) and driving a correction signal onto striplines through a power amplifier. For this feedback a simple 9-tap filter (on each of 936 bunches) is used to adjust the phase for each bunch at the tune frequency.

CONCLUSIONS

As the numbers of IDs and beamlines at Diamond have increased, both the complexity of the storage ring optics and the experimental requirements have increased. The correction schemes described have been developed to keep the storage ring running reliably. Each of the correction schemes described has a well-defined responsibility for maintaining one of the key beam parameters; together they ensure that Diamond is running within tightly-controlled operational specifications.

REFERENCES

[1] I.P.S. Martin et al., in Proc. IPAC2014, TUPRI082, (2014).
[2] Python IOC internal note, Diamond Light Source.
[3] B. Singh et al., in Proc. IPAC2010, THPE088, (2010).
[4] B. Singh et al., in Proc. IPAC2011, WEPC042, (2011).
[5] B. Singh et al., in Proc. IPAC2013, TUPWO057, (2013).
[6] M. T. Heron et al., in Proc. ICALEPCS2009, THB003, (2009).
[7] I.P.S. Martin et al., in Proc. IPAC2013, MOPEA071, (2013).
[8] I. Uzun et al., in Proc. ICALEPCS2011, WEPC10, (2011).