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A Feed-Forward Procedure to Counteract Orbit Distortions and Photon Beam Displacements from Insertion Device Operation at the SLS

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INTRODUCTION

Insertion devices (IDs) of different types provide light of high brilliance to experimenters at the Swiss Light Source (SLS). The IDs include hybrid wigglers, in-vacuum undulators, and special undulators for the generation of elliptically polarized light, positioned in the straight sections of the storage ring. Two fundamental requirements for experimenters are that the operation of a given ID is transparent to other beamlines and that the photon beam delivered to the experiment remains stable at all times. Changes in the gap and phase parameters of an ID, however, cause variations in the ID error field which distorts the electron beam orbit. The effect on the emerging photon beam is a displacement in both angle and position, which if too prominent, will disturb the experimental measurement at the beamline. In order to satisfy these two experimental requirements, the distortions caused by the ID error field must first be quantified, and then precisely corrected by determining the appropriate kick strengths to be applied to corrector magnets strategically straddling the ID. Since the dependency of the required corrector currents with ID parameter is a reproducible quantity, the acquired data may then be usefully employed in a feed-forward scheme that counteracts the anticipated ID effects *a priori*. Such an approach further reduces the burden on the global orbit feedback system, which would otherwise be required to act on the entire complex of ring correctors to moderate the resulting distortions *a posteriori*. The methodology and application of a local correction scheme is presented. In particular, use of recently installed X-ray beam position monitors (XBPMs) [1] in the correction algorithm to constrain the photon beam to a specified location is emphasized.

EXPERIMENTAL PROCEDURE

The measurement procedure and correction scheme has encompassed several renewed efforts as our understanding of the effects of the different ID types has increased, coupled with the incorporation of newly commissioned XBPMs in the beamline front-ends. In a first phase, the data were experimentally determined by observing the variation of the electron orbit as a function of the ID parameter(s). The orbit control configuration comprises a total of 73 digital beam position monitors (DBPMs) and associated correctors. The difference in orbits between a reference orbit and that taken after a change in ID parameter is recorded and the corrector deflection angles required to minimize the orbit difference are determined through use of an accelerator model. The corresponding corrector currents are then applied.

While this procedure proved effective in correcting the closed orbit, significant displacements to the photon beam position, as the ID parameter is varied, are nevertheless evident in the beamline due to internal ID steering effects. In an effort to constrain the residual photon beam to a fixed position, data from special analogue 'fast' beam position monitors (FBPMs), located immediately upstream and downstream of each insertion device, were subsequently incorporated into the calculation of the correction. The FBPMs are part of the machine interlock system and do not take part in the global orbit feedback; here they are also being used to confine the electron beam to a straight line with predefined positions at the entry and exit of the ID. The particle beam trajectory *internal* to the device can however deviate considerably from the straight-line fit between the FBPMs as the gap changes. With this in mind, a number of beamlines have recently been equipped with XBPMs at the

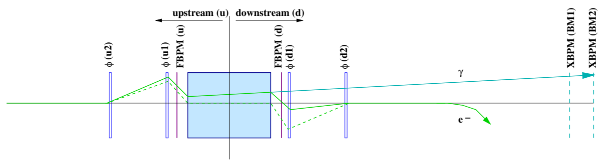


Figure 1: Electron beam trajectory through the insertion device and the emerging photon beam; ϕ represents the deflection angles applied to the inner (u1, d1) and outer (u2, d2) correctors to counteract the ID edge kicks that result in the electron path displayed by the solid (green) line; the intended electron trajectory, after correction, is indicated by the dotted (green) line.

front-end. Since these measure photon beam positions directly, their inclusion in the correction algorithm provides a more stringent confinement of the emerging photon beam. Fig. 1 illustrates the electron trajectory through the ID before and after the intended correction.

High Level Application

A Java based high-level application has been developed to direct the measuring and correction procedure. Access to the low-level hardware and accelerator model, as required to determine corrector kick strengths, is accomplished through use of a CORBA middleware layer [2]. A number of details pertaining to the correction configuration are determined at run start. These include the gap and shift (if applicable) stations to feature in the scan, the maximum number of iterations in a correction cycle per ID setting, the selection of four local correctors together with their maximum allowed currents, and weighting factors for the FBPMs and XBPMs to be used in the fit; a greater weight for XBPMs places the emphasis on the photon beam location at the front-end. The XBPM position to which the photon beam is to be steered may also be configured. Indeed, while the software structure has been developed so that the whole procedure can be operated in auto-pilot mode, the possibility also exists for the user to interact with the procedure allowing, for instance, measurements at desired gap (and shift) stations to be repeated and new reference values to be established whenever required; the latter may prove useful in data acquisition runs whose time periods are of the order of the orbit drift scale.

ID Scan Procedure

ID scan measurements are performed on a warm machine with top-up operation enabled to sustain thermal equilibrium. Data are not, however, collected during injection so as to avoid possible glitches in the orbit. A reference orbit is taken at a predefined ID setting, which typically corresponds to the largest gap value of interest to users and for which calibrated XBPM data is available [1]. The ID is then moved to its first station and the effect on the orbit is observed and recorded. In a first iteration, the correction kicks are determined from the orbit difference alone, using the appropriate algorithm, and relevant data acquired from the accelerator model. The corresponding currents are then applied to the specified correctors. The effect on the orbit is again observed and recorded. The data from the FBPMs and XBPMs, which are to be used for the steering of the photon beam, are first included in the subsequent iteration. In this second iteration, *in addition* to a further orbit analysis, the differences in FBPM and XBPM positions with respect to their reference values are also analyzed and the predicted correction kicks are added to the corrector kicks as determined from the present orbit difference analysis. This two-step procedure in this iteration is required as the two components of the correction, i.e. orbit correction and photon beam correction, do not necessarily act in the same direction. The use of weights for FBPMs and XBPMs is also important; this is because it may also prove difficult to keep both the FBPMs and XBPMs to their reference values. Not surprisingly, it is of benefit to give bigger weighting factors to the XBPMs since maintaining photon beam stability at the beamline is the ultimate goal. The above two iterations are repeated until agreement with the reference orbit and photon beam reference position is achieved or the maximum number of iterations is reached. The correctors are returned to their nominal reference values (typically zero) and the ID is moved to its next station. The cycle of iterations is repeated until all selected ID stations have been addressed.

Data Analysis and Feed-Forward Generation

Data from all iterations are recorded in a database and are made available for immediate analysis and examination, both in numerical and graphical form. The most relevant distributions that reflect the effectiveness of the correction procedure are the rms values of the orbit and the XBPM positions which indicate the movement of the photon beam at the beamline. The resulting strength of the corrector currents is also examined; these are required to be well within saturation values. The final corrector currents are then fitted to an appropriate function and feed-forward look-up tables are generated from the output of the fitting procedure in a format that can be readily downloaded to the low-level EPICS based control system. The feed-forward tables are implemented at the local processor level and applied at a rate of ten Hz. The look-up tables are then verified by observing the orbit rms values and the XBPM readings as the ID parameter changes. The entire gap scan procedure, feed-forward generation and subsequent verification requires only a few minutes for simple insertion devices such as the planar in-vacuum undulator.

PRESENTATION OF RESULTS

Results presented here stem from an analysis of the 10S beamline. The layout of the straight, shown in Fig. 2, is typical of the short sections at the SLS and hosts an in-vacuum undulator of type U19. The correction configuration comprises two straddling ID correctors, two ring correctors, which are otherwise part of the closed orbit feed-

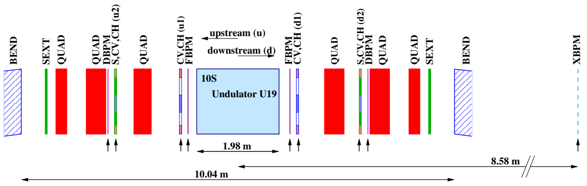
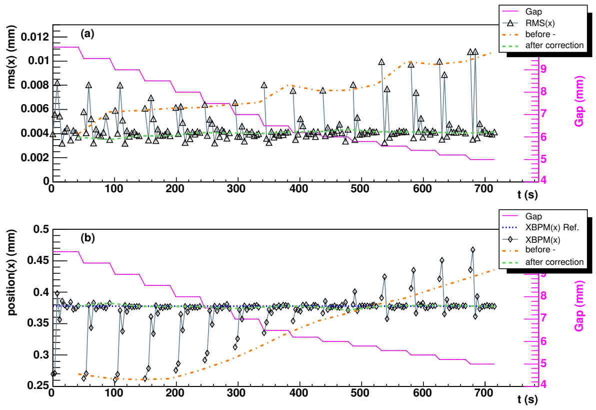


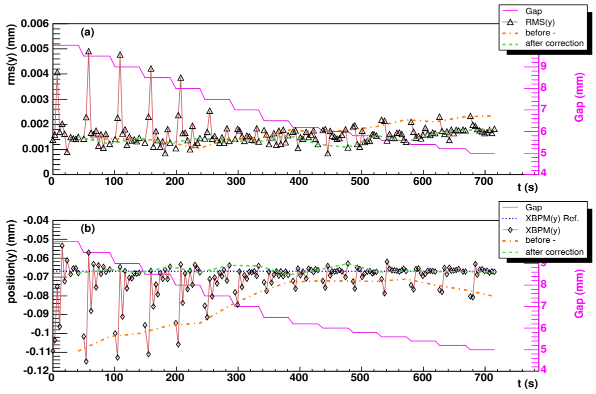
Figure 2: Layout of the 10S short straight section. The correctors and BPMs featuring in the correction procedure are indicated.

back system, two FBPMs and a single XBPM in the front-end. Fig. 3 displays the effect of the correction procedure on the most critical variables, these being the orbit rms values and the XBPM positions. The final ID parameter dependent correction currents are shown in Fig. 4 and are well described by a 3rd degree polynomial. The fitted values serve as the set-points for EPICS channels that form the feed-forward tables. They can be downloaded to the hardware control system for immediate verification. It is stressed that feed-forward tables are only implemented for the two straddling, inner correctors (Fig. 4(a)); the orbit feedback system provides the solution for the outer, ring correctors. This is the case for all short sections where space restrictions allow for only two dedicated ID correctors. The medium and long straights, on the other hand, are equipped with four local correctors for which feed-forward tables can be implemented.

The results show the effectiveness of the correction procedure in flattening the orbit and stabilizing the photon beam. In particular, the XBPM readings at the various gap positions, after correction, demonstrate a point-to-point photon beam stability of 5 μm in x and y, which corresponds to a photon pointing stability at the target area of 0.6 μrad in both the horizontal and vertical plane. The inclusion of XBPM data into the closed orbit feedback system further prevents the photon beam from drifting with time from its designated location [3].



(i) horizontal



(ii) vertical

Figure 3: The effect of the correction cycle for a series of gap values on the (i) horizontal and (ii) vertical components of (a) the orbit rms and (b) the photon beam position at the XBPM. The dashed (green) line connects the variable values at the final iteration of each cycle, i.e. after correction; the dashed-dotted (orange) line connects the initial variable values, i.e. before correction, but *displaced in time* to the point of final iteration, in order to aid visual comparison. The dotted (blue) line in (b) represents the reference XBPM value to which the fit corrects.

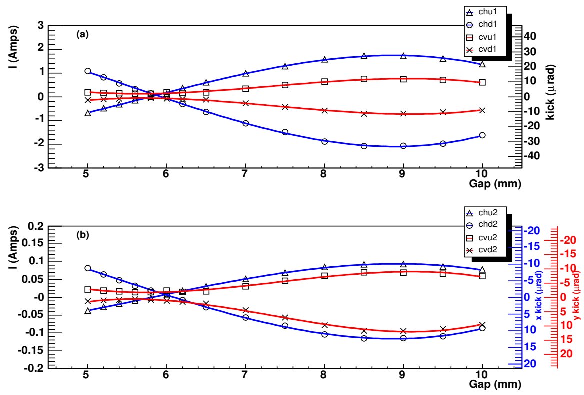


Figure 4: Corrected horizontal (red) and vertical (blue) currents and kick strengths versus gap for the (a) inner and (b) outer correctors (see Fig. 2). The various kick scales reflect the different corrector calibration constants.

CONCLUSION

The effect of insertion device operation on the electron beam orbit and the emerging photon beam has been investigated. The orbit distortions and photon beam displacements have been quantified and corrected, leading to a feed-forward procedure that acts on designated correctors located in the proximity of the insertion device. A photon pointing stability at the sub-microradian level has been achieved for beamlines equipped with recently calibrated X-ray beam position monitors. The integration of a second X-ray monitor upstream of the beamline will further constrain the photon beam in both position and angle. A detailed account of this work, including derivation of the correction algorithm and correction procedures developed for more complex insertion devices such as the UE212 electromagnet and APPLE II devices, is in preparation.

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