PROGRESS ON THE TRANSPARENT REALIGNMENT OF THE DIAMOND STORAGE RING

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Abstract

The mechanical alignment of Diamond Storage Ring is achieved by means of a 5-axis motion system under remote control via the EPICS toolkit from the Diamond Control Room. We have completed the first phase of the realignment program meant to improve the mechanical alignment of the machine by carefully moving the magnet girders with a virtually zero impact on the associated beamlines, hence the name Transparent Realignment (TR). During this phase we have equipped and realigned 3 out of 24 cells, involving two beamlines. We have also tested and perfected the technique to execute a move with live beam and total remote control of the realignment process. The program has entered a second phase entailing the commissioning of 6 more cells. Details of tests on the machine are reported.

INTRODUCTION

The realignment of a storage ring (SR) is key to reach low vertical emittances, down to few pm or even sub pm [1, 2]. Today the realignment or control of the alignment status of a machine is part of routine programmes in many facilities. At Diamond this request became more important after low coupling (C=0.3 %, ϵ_y = 8 pm rad) became the standard user mode in March 2013. Large mis-alignments can be detrimental in the horizontal plane as well, causing photon beam mis-steering towards the beamlines. In order to reduce the potential impact of alignment moves on the beamlines a strategy has been devised and proved effective on several tests since the end of 2013. "Golden" Offsets (GO) re-defining the zero at the primary Beam Position Monitors (BPM) facing an ID straight, restore the orbit as it was prior to the move, making the realignment transparent to the beamline [3]. With the exception of the recently installed cell-2, hosting two girders, all the remaining 23 cells in the SR are constituted by a triplet of girders where magnets are positioned. A new remote girder control system (GCS), capable of moving three girders at a time has been installed and used since 2015 [4]. It requires prior commissioning of the girders meant to be moved, which consists in the installation of Linear Variable Differential Transformers (LVDT) to limit possible excessive moves, control electronics installed in the nearby control and instrumentation area and a series of tests to verify the response of each of the 5 axes. In 2015 we successfully realigned straight-05 and tested for the first time the alignment of the central girder of cell-6 with a 20mA circulating beam, where the current position of the girder was monitored both by the control system and by reading corrector magnet (CM) variations. In April 2016 a control issue during a standard commissioning of cell-21 imposed a technical stop to the project in order to identify the reasons for the failure. Due to a series of commitments, such as the installation of the new DDBA cell-2 in the SR [5], the delay had to be protracted for nearly one year. At the beginning of 2017 a newly designed protection system for girder motion was ready to revive the TR program.

SURVEY ASSISTED GIRDER ALIGNMENT (SAGA)

Horizontal Realignment of Straight-14

The horizontal and vertical planes are periodically surveyed at Diamond, as shown in [3]. Thanks to this information we can prioritize the choice of the girders needing attention and define the move. At the end of 2015, a beam tilt in the horizontal plane of about -35 μrad (inboard) was observed by beamline I14 and confirmed by survey data. This is shown in Fig. 1 where the mis-aligned orbit (solid blue line) is pointing inboard with the aforementioned yaw.

Table 1: Girder moves and GOs for straight-14 realignment. GO(13,7)=-100 μm and GO(14,1)=+100 μm were in force from January 2016 mimicking the effects of the mechanical move (see Fig. 1). The offsets were removed on April 10th 2017, after completing the mechanical alignment

date	girder	sway (μm)	yaw (μrad)	GO (13,7) (μm)	GO (14,1) (μm)
10042017	C13G1	-27	-72	0	0
	C14G1	158	8		

In agreement with the beamline it was decided to realign the straight by zeroing the tilting angle. This can be achieved by moving the girders of cells 13 and 14 facing straight-14 (C13G3 and C14G1 in our naming convention). For completeness we also studied the effect of moving the central girders (C13G2 and C14G2) to improve the overall alignment of cells 13 and 14. The orbit after the alignment is represented by the dotted green line in Fig. 1, and is clearly flat in the ID region at the centre of the picture. While waiting for the time slot to execute the move, two horizontal offsets of ∓ 100 μm were placed at the primary BPMs facing the straight in order to let I14 continue with its commissioning phase. This produces an orbit represented as a dotted yellow line in Fig. 1, perfectly overlapping the future realigned orbit. A summary of the changes implemented in the machine is shown in Table 1. On April 10th 2017,

ISBN 978-3-95450-182-3

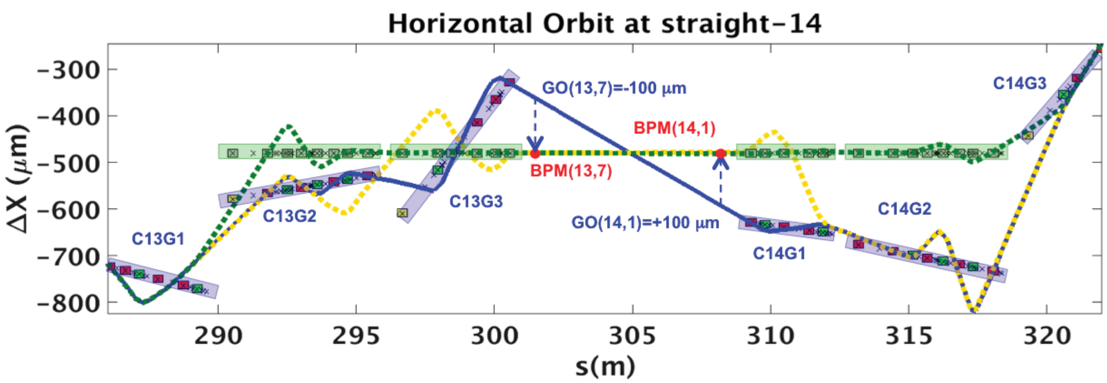

Figure 1: Planimetric view of straight-14 region showing girder positions (shaded blue boxes) before April 10th 2017. The smaller boxes represent quadrupoles (red), sextupoles (green) and dipoles (yellow) sitting on the girders. The solid blue line pointing at -35 μrad inboard is the equilibrium orbit for the mis-aligned configuration. When GOs are placed at BPM(13,7) and BPM(14,1) (red dots) the orbit is corrected to produce a zero yaw beam in agreement with beamline I14 request (dashed yellow line). The mechanical realignment of girders C13G3 and C14G1 is sufficient to reproduce the same orbit in the straight (dashed green line). A better alignment can be achieved by moving C13G2 and C14G2 too (shaded green boxes).

we removed the BPM offsets and realigned the system with the live beam procedure already tested in 2015 [4]. This consists in performing the move with a low current beam (20 mA) circulating in the SR, while running the fast orbit feedback to maintain a stable orbit. For moves in the horizontal plane the RF feedback is also active, ensuring the cancellation of dispersive patterns due to path variations of the orbit. Variations in the Horizontal CMs (HCM) can then be used to infer the actual position of the girder, as described later in this paper. This procedure requires a reliable control

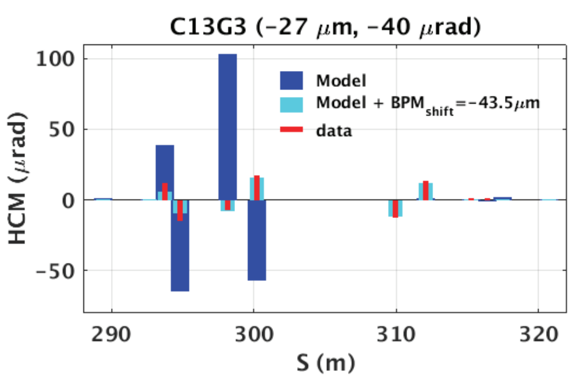

Figure 2: HCM changes for a sway of -27 μm and a yaw of -40 μrad on C13G3. Predictions (dark blue bars) are in total disagreement with the machine response (red bars). Agreement is completely restored when primary BPM shifts are introduced as described in the text (cyan bars).

system and a good modelling of the lattice response to girder moves. During the alignment session we observed large discrepancies between the imparted moves and the values predicted from the horizontal corrector variations. After a thorough examination, we found that the primary BPMs facing the straight were not stable when the move was imparted. Primary BPMs are not sitting on a girder, being connected to the vacuum chamber by means of bellows to

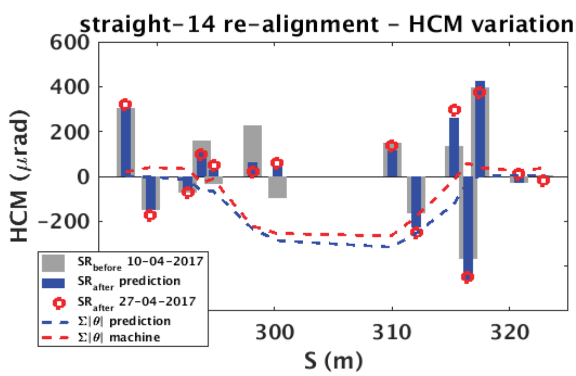

Figure 3: HCM variations after the realignment of straight-14. The initial configuration (grey bars) changes into the one represented by the red dots. The predicted new values (blue bars) match fairly well with the machine. The dashed lines show the net CM strength variation after the move.

decouple any motion in the nearby girders. Linear encoders monitoring the position of primary BPMs in both planes, revealed that during the alignment, the motion of the nearby girder was partly transferred to the adjacent BPM. When these measured displacements are introduced in the model for girder motions, the agreement between predictions and data is compelling (see Fig. 2). While detrimental during the monitoring of the move, these BPM shifts are completely cancelled after a beam-based alignment (BBA) cycle. HCMs before and after the move are shown in Fig. 3, showing a good agreement with our predictions. The increase in CM strength in C14 is due to the step between G1 and G2 created after the alignment. Calculations show that a large reduction in CM strength can be achieved if the central girders (C13G2, C14G2) are aligned too, as illustrated in Fig. 1. The discrepancies between model and machine experienced during straight-14 alignment, and later explained as due to an unwanted shift of the primary BPMs left us unsatisfied

ISBN 978-3-95450-182-3

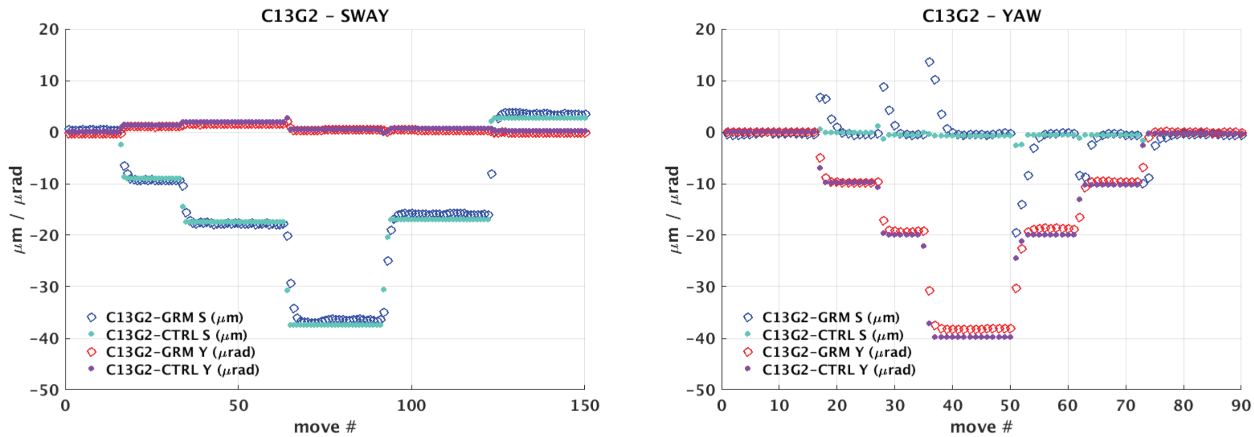

Figure 4: On-line girder move monitoring. Cyan (purple) dots represent the sway (yaw) readings from the GCS, blue (red) circles show the sway (yaw) values calculated from HCM changes in the machine (see text). Left: pure sway move on C13G2, showing a good agreement between the GCS readings and the inferred sway from HCM variations. Virtually zero yaw is recorded, as expected. For a pure yaw move (right picture) only yaw changes are visible and the agreement between the control readings and the inferred yaws is once more remarkable.

about our ability at monitoring girder moves as they happen. An extra test was therefore conducted in order to clear any doubt about these issues. Small sway and yaw moves were performed on C13G2, comparing the reading from the GCS against model predictions. These are obtained by monitoring the variations in the CMs and using an inverse Girder Response Matrix to calculate the move that generated a specific corrector pattern. Results are summarized in Fig. 4 where can be seen how sway and yaw moves can be reliably tracked by reading the HCM variations in the machine.

Vertical Realignment of Straight-06

Using the same technique described in the previous paragraph, the realignment of straight-06 was implemented on May 9th 2017. For this case beamline I06 explicitly requested to have the orbit back to its original fashion. Survey data were used to define the move and the aforementioned live beam procedure to execute it. Move parameters are shown in Table 2, together with the GOs used to make the move transparent to the beamline. The effect of the move on cell-5 and cell-6 Vertical CMs (VCM) is shown in Fig. 5.

Table 2: Girder moves for straight-06 realignment and GOs ensuring the TR condition

date	girder	heave (μm)	pitch (μrad)	GO (5,7) (μm)	GO (6,1) (μm)
09052017	C5G3	0	75	-88	63
	C6G1	-85	21		

CONCLUSIONS AND FUTURE WORK

The realignment of straight-14 confirmed that we can impart girder moves remotely from the control room, monitor their position during the motion and steer the beam with a

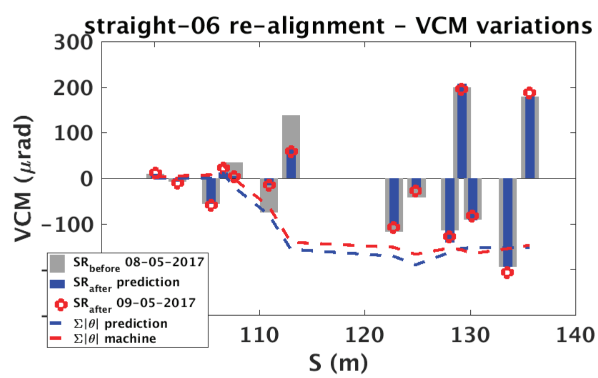

Figure 5: VCM values before (grey bars) and after the realignment of straight-06 (red dots). Predictions for the move (blue bars) are in good agreement with data. The dashed lines show the net CM strength variation after the move.

high level of accuracy. For this case the process involved only the girders facing the straight, however a future realignment of C13G2 and C14G2 should significantly reduce the CM strength in the two cells. During this process we gained a lot of understanding on potential problems affecting primary BPMs when implementing horizontal moves. The realignment of straight-06 closes the first phase of the TR programme, involving cells 4,5 and 6. Straight-14 realignment marks the beginning of the second phase of the TR programme, involving 6 new cells in the SR.

ACKNOWLEDGMENTS

We wish to thank the Operations group and C. Bloomer (Diagnostics) for their support during tests. We are also greatly indebted to P. Quinn (I14) and to S. Dhesi, F. Maccherozzi and T. Forrest (I06) for their patient cooperation both in the preparation and during the implementation of the realignment moves.

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ISBN 978-3-95450-182-3