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FIRST TRANSPARENT REALIGNMENT TESTS AT THE DIAMOND STORAGE RING

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Abstract

The Transparent Realignment (TR) of the Diamond Storage Ring is a program of work to improve the mechanical alignment of the machine by carefully moving the magnet girders with a virtually zero impact on the associated beamlines. The girders can be moved by means of a 5-axis motion system under remote control via the EPICS toolkit from the Diamond Control Room. Currently three cells (three girders in each) have been equipped with a permanent protection system to prevent excessive deflection across each of the inter-girder vacuum bellows. The protection and motion systems are installed in the associated Control and Instrumentation Area (CIA). Full commissioning of the motion and protection systems have been completed. Results from the alignment test sessions are hereby 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.

Care must be taken when correcting for mechanical misalignments, since moves can potentially impact on nearby insertion devices (IDs). The strategy to mitigate this effect has been devised and initially tested at the end of 2013. It consists in the careful use of orbit bumps (Golden Offsets, GO) at the primary BPMs facing an ID straight, that restore the orbit where it was prior to the alignment, as thoroughly described in [3]. In this paper we introduce the new remote control system, capable of moving three girders at a time, and show the results obtained in the realignment of straight-05. We focus on the effects of introducing GOs and subsequently remove them, with the beamline realigning to the new machine configuration. A view to future tests is presented at the end of the document.

SURVEY ASSISTED GIRDER ALIGNMENT (SAGA)

Choice of Cells to be Realigned

The horizontal and vertical planes are periodically surveyed at Diamond, as shown in [3, 4]. In the vertical plane figures are reported as levels of the girder edges respect to a best fit plane, interpolating all the monument levels as measured in a full survey campaign of SR. Figure 1 shows a snapshot of the vertical plane alignment as of June 2014, where variations as large as 600 μm are seen. In order to reduce the magnitude of the realignment moves a smooth curve was fitted to the monument positions whose period is about half of the SR length (561.6 m). The curve is a sine wave with a mildly variable amplitude, and the long wavelength ensures that a realignment to this baseline should be effective while keeping girder moves within few hundred microns. Figure 1 guides the choice of cells 4, 5 and 6 as parts of the lattice to be realigned, in an ideal continuation of the work previously done to align cell 3. The initial highly mis-aligned pattern in cells 4 and 5 (gray segments), has been brought to a more tamed configuration by April 2015, resulting in an overall aligned sequence from cell-3 to cell-5. As described later, this reduced the vertical corrector magnet (VCM) strength used to correct the orbit.

Survey is the primary source of information for the moves imparted to girders. Sometimes, however, the predicted change in corrector strength can be used as a guide to realignment, as indeed happened when realigning straight-05. realignment moves are monitored by the survey team, showing that imparted moves and survey data are in good agreement, with typical monument discrepancies of less than 15 μm.

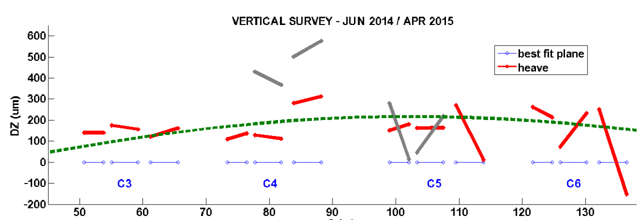

Figure 1: Vertical survey of the Diamond Storage Ring. The red segments join the monuments at girder edges, showing the present situation after the realignment of straight-05, while the gray ones show the state of the machine before it. The dashed green line is a fit to the 148 monument levels, which is used as realignment baseline (see text).

Girder Control

Until mid 2014 girders were individually moved by means of a stand-alone crate connecting a laptop hosting the software to control the 5-axis cam motors that perform a girder move in the corresponding degrees of freedom (sway, yaw, heave, pitch and roll about the s-axis of the girder).

A protection system of Linear Variable Differential Transformers (LVDT) was temporarily mounted to ensure that

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any move would be within pre-defined tolerances. After the summer of 2014 cells 4, 5 and 6 were equipped with a permanent LVDT set-up and commissioned for remote control of the move, with the advantage of having a system always ready for use, and capable of moving a triplet of adjacent girders at a time, usually, but not necessarily, belonging to one cell. The control electronics is now hosted in the nearby CIAs and the control software has been released and can be used directly from the Diamond control room.

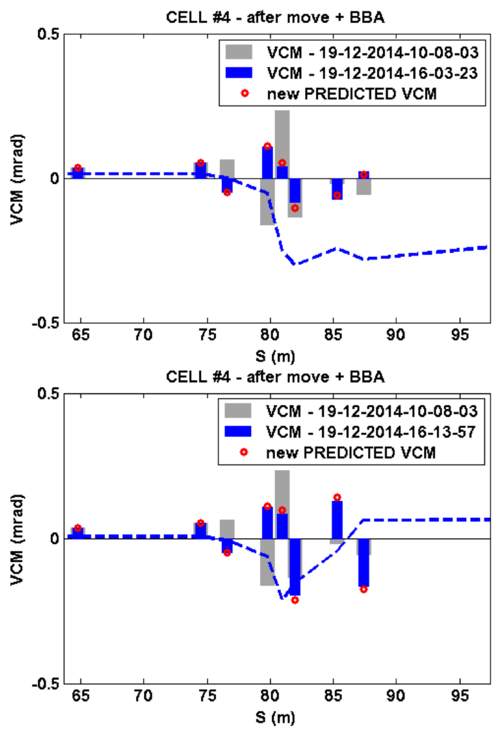

Figure 2: Vertical corrector changes after realignment of cell 4 and four BBA cycles (top) and with the introduction of a GO(4,7)=239 μm to make the move transparent (bottom). (Gray) initial set of correctors, (blue) new corrector pattern, (red dots) predicted VCM strengths. The change in total corrector strength (dashed blue line) becomes positive after the introduction of a GO.

Transparent Realignment of Straight-05

The June 2014 vertical survey, showed how girders 2 and 3 in cell-4 were highly mis-aligned, while the first girder appeared levelled with the upstream cell-3 (see Fig. 1). Girder 2 was then brought to the same level as girder 1, while girder 3 was cautiously moved down by -250 μm only. In order to keep the change transparent to beamline I05, a GO=239 μm at the last BPM in cell 4 (BPM(4,7)) was implemented. Table 1 summarizes moves and GOs set in the BPMs to restore the orbit to its initial position.

The effect of the move followed by a BBA procedure on the VCMs is shown in Fig. 2 (top). The initial corrector pattern (gray bars) turns into a new one (blue bars) and the change is well reproduced by our model (red dots), that includes both the girder moves and the four BBA cycles used

Table 1: Girder moves and GOs for straight-05 realignment. GO(4,7)=239 μm was in force from December to April ensuring the transparency of the move. Note how GO(4,7)=248 and GO(5,1)=62 μm were only implemented on April 8^{th}, and then set to zero after beamline I05 realignment.

move date	girder	H (um)	P (urad)	GO (4,7) (um)	GO (5,1) (um)
19122014	VC4G2	-275	15	239	0
	VC4G3	-250	-17		
08042015	VC5G1	0	87	248	62
	VC5G2	30	-42		

to realign the beam to the quadrupole magnetic centres. It is clear how realigning the cell results in a reduced use of the steerers as can be seen too by plotting the total corrector strength variation $\delta \sum_{i=1}^{172} |\theta_i|$ (dashed blue line), that shows a clear drop to about -250 μrad at the second half of cell-4. When a golden offset of 239 μm is placed at the last

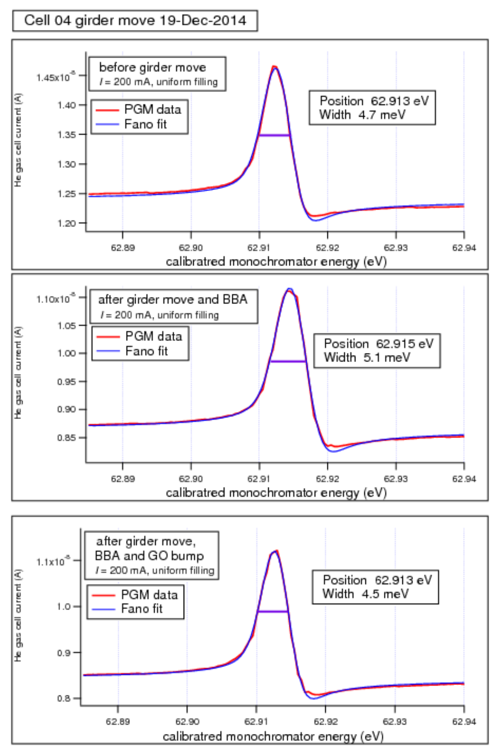

Figure 3: Energy calibration of the PGM beamline system. (Top) initial setting, showing a Helium photo-inoization peak at 62.913 eV and a full width of 4.7 meV. (Middle) after cell-4 is realigned the peak is shifted to 62.915 eV with a width of 5.1 meV. (Bottom) the configuration is perfectly restored when GO=239 μm is implemented at BPM(4,7).

BPM of cell-4, the downstream correctors compensate the change, resulting in a higher overall steerer strength, as seen in Fig. 2 (bottom). In order to validate our ability at setting the orbit where it was prior to the realignment, a figure of merit for beamline I05 was chosen, which corresponds

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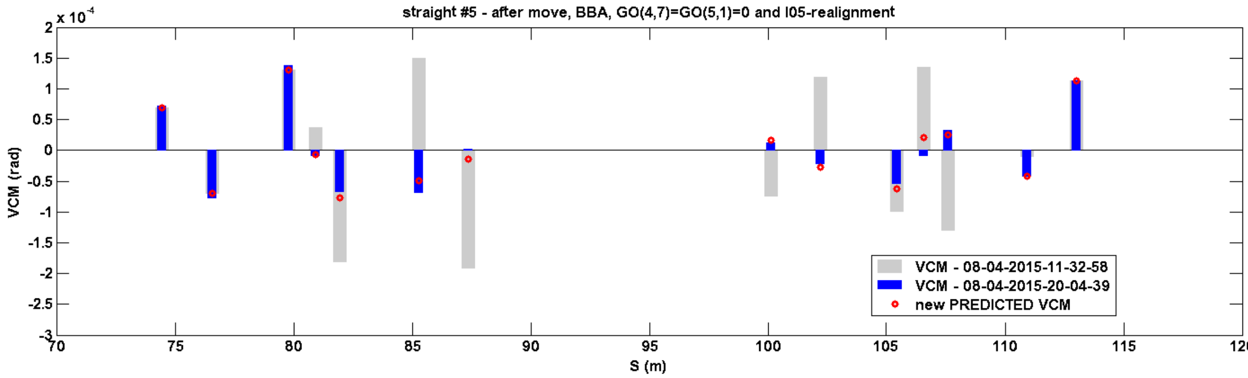

Figure 4: VCM strength reduction after C5G1G2 realignment and the removal of GO(4,7) following the full realignment of I05 beamline. The new VCM pattern in the machine (blue bars) agrees well with model predictions (red dots).

to the resonance peak for a process of photo-ionization induced by a monochromatic beam impinging on a He-filled gas chamber whose secondary electrons are collected and amplified at an anode wire. Energies are scanned around these peaks, by moving the angles of a Plane and Grating Mirror set (PGM) upstream in the beamline. A calibration is used which defines the selected wave-length (energy) as [5]:

$$\lambda_{PGM} = \frac{sin(\beta) - sin(\alpha)}{800(lines/mm)} \quad (1)$$

where α and β are respectively the entrance and exit angle at the grating, and the impinging angle at the plane mirror is $(\alpha + \beta)/2$. While the ionization energy is dictated by nature, the calibration defined by Eq. 1 changes whenever a tilt or heave of the entering electron beam is produced, resulting in an apparent shift of initial energy peak, as seen in Fig. 3 where the top graph represents the initial calibration, the middle plot shows the shifted energy peak due to the realignment of cell-4 and the bottom plot shows a perfectly restored peak (both in position and width) when GO(4,7) is properly set. The level of accuracy is remarkable too, since the calibration shift is of the order of few meV over 62 eV.

Elimination of Golden Offsets and Realignment of the I05 Beamline

The introduction of golden offsets can completely restore the orbit in a straight, as it was prior to an alignment move, and as compellingly shown in the previous sub-section. Unfortunately the correctors facing the straight usually undergo an increment in strength, *de facto* spoiling the initial mechanical improvement. The advantage of introducing a GO bump, however, is in the fact that such parameter can be easily relaxed, should the beamline decide to realign their set-up to the new orbit. This is what in fact happened with beamline I05, that accepted to realign their optics against a realigned machine. In April 2015 we moved the first two girders of cell-5 (see Table 1 and Fig. 1) and removed the GO at the end of cell-4. Figure 4 clearly shows a large suppression in the corrector strength for the VCMs facing straight-05, as expected from our model. The overall reduction in VCM strength is of about 750 μrad (not shown here).

CONCLUSIONS AND FUTURE WORK

The realignment of straight-05, where the ID of the I05 beamline is located, represents an ideal working cycle, where machine realignments are compensated by GOs restoring the initial orbit through the ID (transparent realignment) and where a subsequent realignment of the beamline allows to remove any offset resulting in a better machine configuration too. Despite these successful results, the strategy adopted so far is particularly slow, mainly due to the surveying of the move that requires access to the vault and therefore a beam dump followed by re-injection. The natural progress to avoid this time consumption consists in executing girder movements with the beam circulating in the SR, as done *e.g.*

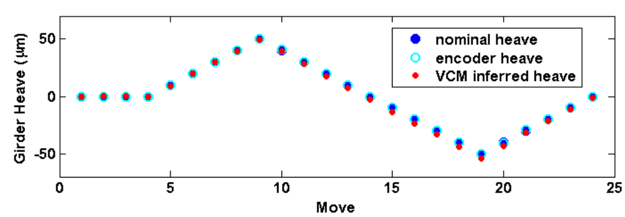

Figure 5: C6G2 heave scan: (blue dots) nominal imparted heave, (cyan circles) heave from remote control encoder readings, (red dots) girder heave inferred from the variation of the vertical steerers.

at the SLS [2]. A test with a 20mA beam has been conducted where girder 2 in cell 6 was heaved up and down in steps of 10 μm while the fast orbit feedback corrected the orbit. Using an inverted response matrix the actual position of the girder can be inferred from the changes in the corrector pattern, as illustrated in Fig. 5. The good agreement between nominal heaves, encoder readings and VCM-inferred positions makes this method particulary promising for future moves. The realignment of straight 6 will conclude the series of TR tests involving cells 4, 5 and 6. The possibility of extending the TR programme to six more SR cells is currently being discussed.

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