BEAM BASED MAGNET ALIGNMENT FOR EMITTANCE COUPLING MINIMIZATION

Rohan Dowd, Greg LeBlanc, Yaw-Ren Eugene Tan, SLSA, Clayton, Australia
Kent Wootton, The University of Melbourne, Parkville, Australia

Abstract

Small errors in magnet alignment can be a significant source of transverse coupling in a storage ring. Beam offsets in the quadrupole and sextupole magnets at the Australian Synchrotron Light Source were measured using a LOCO based orbit response matrix analysis. The results were used to obtain an estimate of the offset in each magnet and these were then used to guide mechanical alignment efforts. A significant reduction in the uncorrected beam coupling was observed after these corrections, with a corresponding reduction in corrected coupling.

INTRODUCTION

A method of measuring sextupole offsets based on Orbit Response Matric (ORM) analysis has been previously studied at the APS and showed in general, good agreement with BPM offsets [1]. A method based on this approach has been applied to the storage ring of the Australian Synchrotron Light Source (ASLS) to study and correct misalignments of all of the multipole magnets. The main aim of this work has been to reduce sources of coupling in efforts to achieve an ultra-low vertical emittance, ε_y. The ASLS had good success in achieving ultra-low vertical emittance [2], however more recent magnet realignments based on survey data had created a situation in which previous vertical emittance results could not be reproduced. The uncorrected ε_y had risen from 9 pm to 35 pm. The method of sextupole vertical offset determination was shown in previous work [3] to be accurate and valid. This paper will show how these results have been used and expanded on to achieve significant improvements in coupling control.

MEASUREMENT METHOD

The ASLS storage ring is a double bend achromat lattice with the arrangement of magnets and girders in each arc sector shown in Figure 1. Each arc sector has two short girders and one long girder upon which the multipole magnets are positioned. The dipole magnets are on independent girders. The outer focussing and defocussing sextupoles on the short girders are split into families 'SFA' and 'SDA' respectively, while the sextupoles on the long girder between the dipole magnets are designated 'SFB' and 'SDB'.

Sextupole Vertical Offsets

Horizontal and vertical offsets in sextupole magnets create effective quadrupole and skew quadrupole field components respectively. For a sextupole of strength K_2 the effective multipole fields generated by a beam offset of distance $(x - x_0, y - y_0)$ from the magnetic centre (x_0, y_0) can be described as $K_{quad} = K_2 \cdot (x - x_0)$ and $K_{skew} = -K_2 \cdot (y - y_0)$.

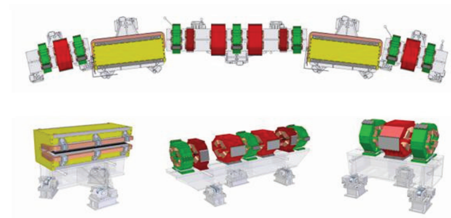

Figure 1: Girder layout for a storage ring arc sector. Quadrupole magnets are red, sextupole magnets are green

A brief overview of the sextupole measurement method is stated below, more detail can be found in [3]. To measure these offsets, the sextupole field K_2 is varied and an orbit response matrix (ORM) measured. The LOCO method [4] is then used to fit quadrupoles and skew-quadrupole components to the sextupole magnets for each setting. Knowing the K_2, K_{quad} and K_{skew} allows you to determine the offset, however there is some ambiguity caused by the LOCO fit results often being 'smeared' over several adjacent magnets if the BPM density and phase advance is not great enough to isolate the effect in the lattice. By measuring K_{quad} and K_{skew} while varying K_2 for a single family only, we can resolve this ambiguity.

The measurements of the vertical offset of the sextupoles in the storage ring is shown in Figure 2. They show that for most sextupole magnets, the beam is higher than the magnetic centre, which allows us to correct these offsets via the placement of shim pieces underneath the base of the magnets to raise the magnetic centre. The shim pieces used were machined to 25 μm thickness divisions (ie, 25 µm, 50 µm, 75 µm, 100 µm...) and were placed under the sextupoles according to the results in Figure 2. After shimming, the same measurements were taken again and the results in Figure 3 show the global mean offset is now less than 10 µm, with most individual magnet offsets less than 25 µm.

Sextupole Horizontal Offsets

Horizontal offsets in sextupoles do not produce coupling and were therefore not the focus of this study. It is not possible to move individual magnets in the horizontal plane, so any correction would need to be made by a global or-

ISBN 978-3-95450-122-9

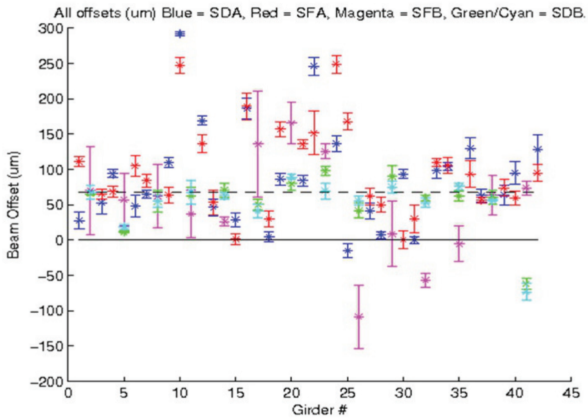

Figure 2: Measurements of the vertical offset in each sextupole against girder position. The dotted black line is the mean offset of all the sextupoles.

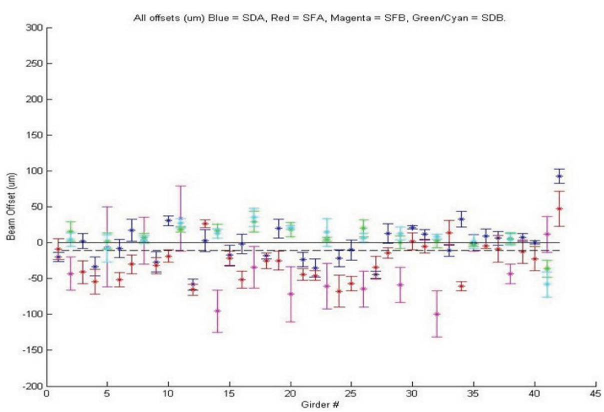

Figure 3: Measurements of the vertical offset in each sextupole after shimming.

bit shift. A cursory examination of the offsets Shown in Figure 4 did not find any significant average offset of the sextupoles in the horizontal plane.

Quadrupole Offsets

The current method of beam based alignment uses a single quadrupole to determine the nominal centre of the nearest BPM. The beam is offset through the quadrupole by using a single corrector and the offset is measured by the nearest BPM. At each offset the quadrupole is shunted and the change in the orbit at the remaining BPMs are plotted as a function of the offset. The centre of the quadrupole is defined as the offset that perturbs the beam the least when shunted. However, the current method can lead to systematic errors.

In the vertical plane this method finds an offset that minimises the first integral $I_1 = \int_0^L B_x(s)ds = -\int_0^L ky(s)ds$ (vice versa for the horizontal plane). If $y(s)$ is constant through the quadrupole, $I_1 = -ky_0L$, and minimising I_1 for all values of k occurs only at the centre of the

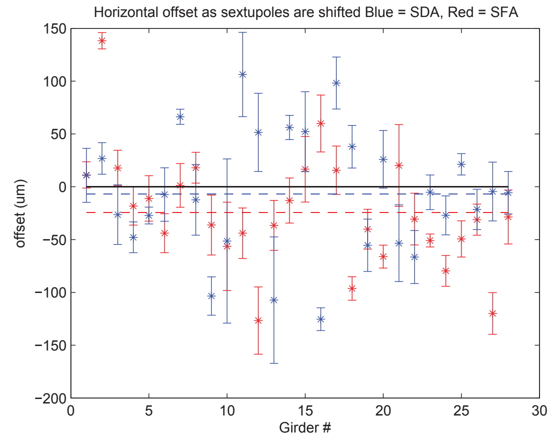

Figure 4: Horizontal offset measured in the SFA and SDA family sextupoles. The mean offset for both families is very close to zero.

quadrupole where $y_0 = 0$. If there is an angle through the quadrupole such that $y(s) = as + b$ then I_1 is minimised if $a = -2b/L$. The solution is any line that passes through the middle of the quadrupole. Therefore if the initial closed orbit has a gradient through quadrupole the solution arrived at will preserve that gradient. In one case the gradient is 10 μrad and for the BPM that is one meter away, the resulting error in the BPM centre calibration is 10 μm from the "true" centre of the quadrupole. Thus any beam based alignment must ensure that the closed orbit is well corrected before proceeding otherwise this will lead to "unseen" offset errors in the magnets.

Quadrupole Rolls

A quadrupole magnet that is rolled by an angle θ about its central axis will produce a skew quadrupole component equal to $K_{skew} = K_1 \cdot sin(\frac{\theta}{2})$

A measurement of the skew component of each quadrupole magnet would potentially allow for a mechanical correction to the magnet to eliminate the skew component. The best correction would be to individually roll each quadrupole, but this is not possible with the girder arrangements in the AS storage ring. Instead, it was done by rolling the girder upon which the magnet sits.

An ORM measurement with the sextupoles turned off was taken. Skew components were then fitted to all of the quadrupole magnets and the corresponding roll was calculated. The fitted rolls are shown in Figure 5 for each magnet girder. Using this information the girders were rolled about their central axis by the amount indicated, while using a laser tracker metrology system to verify the movement. Another ORM measurement was taken with the sextupoles off to verify the corrected rolls, as shown in Figure 6. We can see from these results that we were able to reduce the roll of each girder to less than 0.2 mrad and the possibility exists that another iteration would see a further

ISBN 978-3-95450-122-9

Table 1: Uncorrected and minimized vertical emittance of the storage ring during the various stages of beam-based magnet alignment. Uncorrected ε_y is the emittance of the ring when all skew quadrupoles are turned off.

Lattice Conditions	Uncorrected ε_y (pm)	Minimized ε_y (pm)
Uncorrected	36.8 ± 5.9	8.3 ± 2.3
Uncorrected, sextupoles off	30.4 ± 4.8	6.0 ± 1.4
Sextupoles corrected	35.8 ± 6.2	5.4 ± 1.9
Sextupoles and quadrupoles corrected	12.8 ± 2.4	0.34 ± 0.06

reduction, however due to mechanical consideration (slip and settling of girders after alignment) we do not expect to be able to do better than $\pm$ 0.1 mrad.

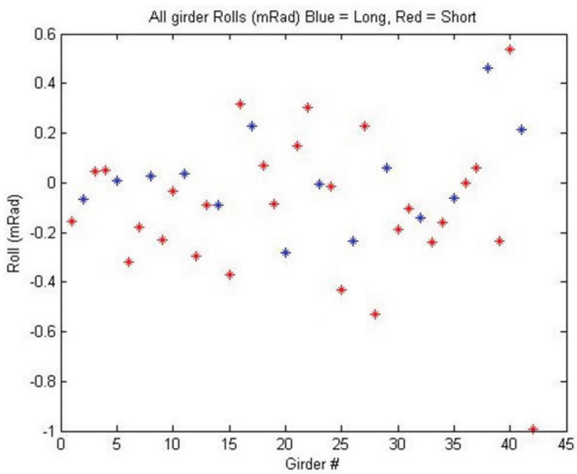

Figure 5: Calculated girder rolls before correction

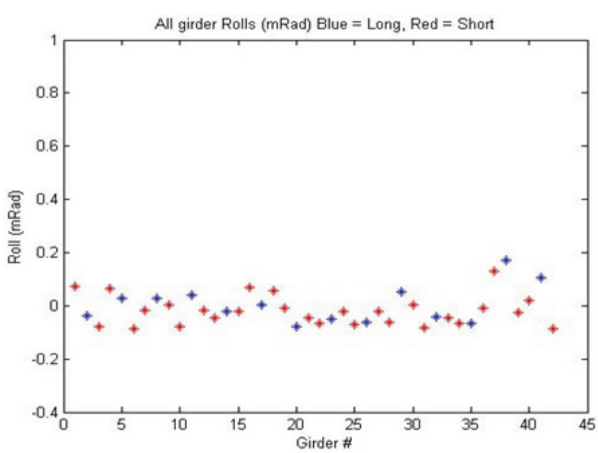

Figure 6: Calculated girder rolls after correction

RESULTS

Using a calibrated model based on the LOCO analysis of coupling and dispersion sources, we can calculate the vertical emittance of the storage ring. This method was shown in [2] to give results quite consistent with other coupling measurement techniques. The results of the analysis of the various lattice conditions are shown in Table 1. It can be noted that correcting the sextupoles did not yield a significant improvement in the uncorrected ε_y but did improve the minimal achievable ε_y and compares well with what can be achieved by turning all the sextupoles off. The measurements of the fully corrected ring now indicate that the vertical emittance can be corrected to below 0.4 pm. This value would be of the same magnitude as the quantum limit of vertical emittance of our storage ring (0.35 pm). We are currently working on a comprehensive measurement of this emittance using a combination of Touschek lifetime analysis and results from vertical undulator photon beam measurements [5].

CONCLUSION

Using ORM based analysis we have been able to identify and correct vertical offsets and rolls in individual multipole magnets around the storage ring. Offsets could be corrected down to around 25 μm in most cases and rolls to less than 0.2 mrad. This has enables us to not only regain the ultra-low coupling conditions previously reported, but also allowed for significant improvements in coupling control.

REFERENCES

[1] V. Sajaev, A. Xiao, "Simultaneous Measurement of All Sextupole Offsets Using the Response Matrix Fit", IPAC'10, Kyoto, Japan, May 2010.

[2] R. Dowd, M. Boland, G. LeBlanc, and Y-R.E. Tan, Phys. Rev. ST Accel. Beams, **14**, 012804 (2011) .

[3] R. Dowd, Y-R.E. Tan, "Beam Based Sextupole Alignment Studies for Coupling Control at the ASLS", IPAC'11, San Sebastian, Spain, September 2011.

[4] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", Nuclear Instrumentation and Methods, **388** (1997), 27-36.

[5] K. P. Wootton, et al. "Observation of Picometer Vertical Emittance with a Vertical Undulator", Phys. Rev. Lett., **109**, 194801, (2012).