BEAM BASED SEXTUPOLE ALIGNMENT STUDIES FOR COUPLING CONTROL AT THE ASLS

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Abstract

Offsets in sextupole magnets can be a significant source of coupling in a storage ring and hinder efforts to minimize the vertical emittance. Beam offsets in the sextupoles at the Australian Synchrotron Light Source were measured using orbit response matrix analysis in LOCO with differing magnet strengths. The results were used to obtain an estimate of the offset in each sextupole.

INTRODUCTION

Minimisation of the vertical emittance has been studied at the Australian Synchrotron Light Source (ASLS) [1] to achieve a vertical emittance between 1-2 pm. The minimisation technique uses an Orbit Response Matrix (ORM) analysis to determine the coupling from magnet misalignments in the storage ring and correct for them using applied skew quadrupole fields. Magnet misalignments that can cause transverse coupling in the beam motion include rolls in quadrupole magnets and offsets in sextupoles. While this method did provide information about the magnitude of coupling being introduced by the various magnet misalignments in the storage ring, it did not provide any information about the type of misalignment. While it is possible to determine large misalignments from the mechanical survey data of the magnets and girders, accurate measurements of the magnetic centre of the magnet in relation to the beam are hampered by uncertainties about the offsets of the magnetic centres from the mechanical centres of the multipole magnets. If the type and magnitude of the misalignments are known from beam measurements however, steps can be taken to mechanically compensate these misalignments.

A method of measuring sextupole offsets based on ORM analysis has been previously studied at the APS and showed in general, good agreement with BPM offsets [2]. This method has been applied at the ASLS to study the sextupole offsets in the storage ring. The accuracy of these measurements have been tested using offset beams and by individual mechanical offsets of sextupoles and the results are presented in this paper.

OFFSET MEASUREMENT METHOD

The feed down effects from horizontal and vertical offsets in sextupole magnets create quadrupole and skew quadrupole fields respectively. For a sextupole of strength K_2 the effective fields generated by an beam offset some distance $(x-x_0, y-y_0)$ from the magnetic centre (x_0, y_0) can be described as:

$$\begin{aligned} K_2.(x-x_0) &= K_{quad} \\ K_2.(y-y_0) &= -K_{skew} \end{aligned} \qquad (1)$$

If the strength of the Sextupole magnet K_2 is varied then the effective quadrupole or skew quadrupole field seen by the offset beam also changes. If the quadrupole or skew quadrupole terms can be measured then the offset of each magnet can be determined. In this analysis we are primarily interesting in reducing the sources of coupling in the machine and have therefore concentrated on the vertical beam offsets in the sextupole magnets.

There are 4 families of sextupole magnets in the storage ring. They are denoted as SFA, SDA, SFB and SDB and each individual magnet has its own power supply. The SFB, SDB magnets are located between the dipoles in regions of high dispersion and are therefore mainly used for chromatic adjustments. The SFA and SDA magnets are located on the short girders in each arc sector, outside of the dipole magnets and are mainly used for harmonic control. The beam position monitors (BPMs) are located next to each sextupole magnets. The layout of the magnets in the arc sectors is shown in Figure 1.

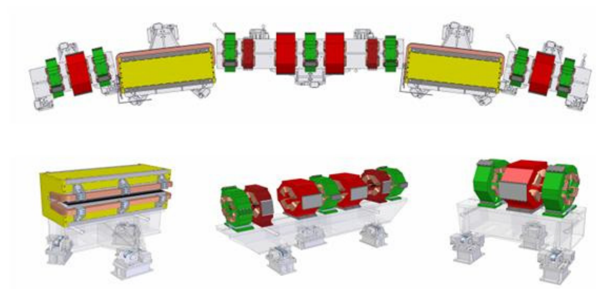

Figure 1: Girder layout for a storage ring arc sector. Sextupole magnets are Green

To measure the beam offset in the sextupole magnets an ORM analysis was conducted for varying sextupole magnet strengths. The response matrix fitting uses the LOCO technique [3] and determines local skew quadrupole strengths that must be applied to the machine model to match the measured response. In order to fit skew fields generated by sectupole offsets and quadrupole rolls, the storage ring lattice model includes skew quadrupole terms in each of the multipole magnets.

While we do have individual control over the sextupole magnet currents, for speed of measurement the scan was broken into separate scans of each of the four sextupole families. It should be theoretically possible to scan all sextupoles simultaneously, however we find that the response matrix fit has difficulty localising the fitted skew fields when there are multiple magnets between a pair of BPMs. By only scanning one family at a time, we ensure a good physical separation between the magnets being scanned, which allows for a more accurate fit. Each sextupole family was set to a number of lower currents (exact values depended on wether beam could be stored with those settings), the orbit was corrected to 'zero' and a response matrix measurement taken.

The fitted skew quadrupole moments for each magnet were then plotted against the sextupole strengths and a linear gradient extracted. This gradient of K_{skew}/K_2, by equation 1 will give the vertical offset of the beam in the sextupole magnet. The error of the gradient fit is used to determine the error in the offset.

In a similar way, by looking at changes in fitted quadrupole moments in the ORM analysis, the horizontal offset can be determined. A preliminary look at the horizontal offsets was done and the mean offset was found to be only $\sim 20\,\mu$m and within error of zero. As we are primarily concerned with coupling minimisation, the rest of this paper will concentrate on the vertical offsets.

It was found that due to the larger number of magnets between BPMs in the long girders between the dipole magnets, the ORM fitting errors are larger. LOCO often distributes the skew terms generated by one sextupole into the adjacent magnets, requiring skew terms from all the magnets to be summed to find the total change in skew component. This increases the error in the K_{skew}/K_2 determination. The SFB magnets in particular suffer from this as they sit in the middle of the girder and consequently often have large uncertainties.

RESULTS

The results of the offset scan are shown in Figure 2. They show that there is a mean offset of $67.8 \pm 14.3\,\mu$m in the sextupole magnets. This is interesting as nearly all sextupoles show a positive offset and this indicates some kind of systematic error in either mechanical alignment or BPM calibration. The sextupole and quadrupole magnets share the same girder, so girder alignment should not be the cause. The BPMs are calibrated by finding the magnetic centre of the quadrupole magnets, so it is possible that the magnetic centres of the quadrupole and sextupole are not at the same height. There may also be a systematic error in the BPM calibration, but this has been checked by modifying the calibration routine and no significant changes were observed. So far, the cause of this offset is not known. The larger offsets found in girders 15 to 25 agree well with other indications, such as large orbit corrections in that area, that there are some alignment issues with the magnets there. This is currently being investigated.

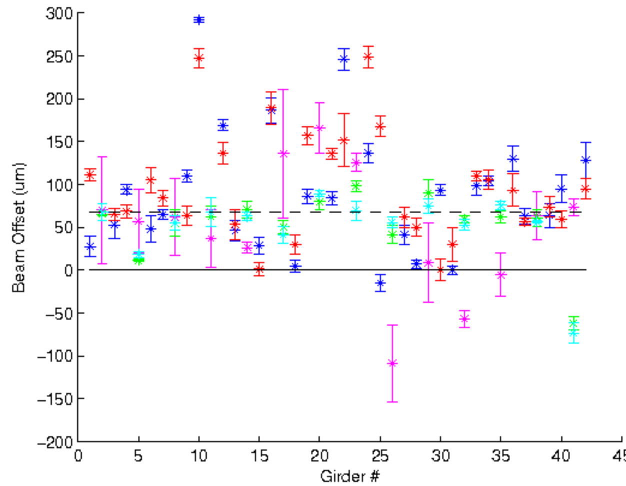

Figure 2: Vertical beam offset in all sextupole magnets. Each sextupole offset is plotted according to girder number around the ring and colour coded by family - SFA (blue), SDA (red), SFB (magenta), SDB (green/cyan). The solid black line shows zero offset. The mean offset of all sextupoles is $67.8 \pm 14.3\,\mu$m and is shown by the black dotted line

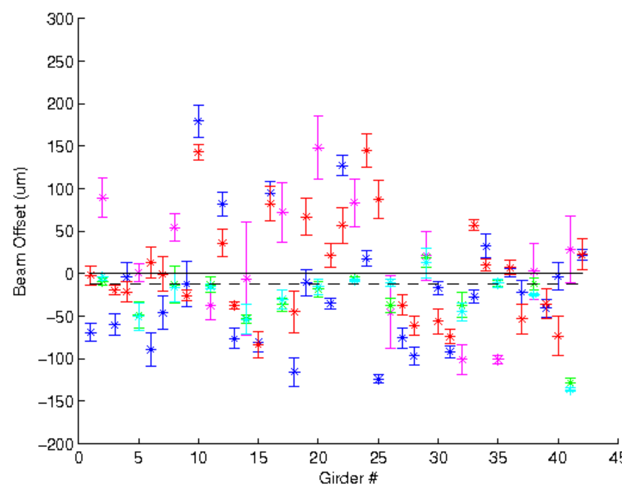

Figure 3: Vertical beam offset in all sextupole magnets after applying a $-100\,\mu$m offset to the beam. Colours again denote magnet family - SFA (blue), SDA (red), SFB (magenta), SDB (green/cyan). The mean offset, $-11.4 \pm 14.6\,\mu$m, is shown by the black dotted line

CROSS CHECKS

The results were surprising because they showed a mean offset of all the sextupole magnets in excess of the alignment survey tolerances. The offsets found were checked against factory measurements of mechanical vs magnets centres for the sextupoles and no clear correlation was seen. We therefore conducted several cross checks to confirm the accuracy of the offset measurements

The first cross check involved applying an offset to the electron beam around the ring and remeasuring the offsets.

Table 2: Results of shimmed magnet offset measurements. The applied shim raises the magnet and therefore the beam offset shifts in the negative direction

Magnets	Original Offset (µm)	New Offset (µm)	Delta (µm)	Applied Shim (µm)
Sector 9, SFB	-108.4 ± 44.6	-249.3 ± 7.2	-140.9 ± 45.2	150
Sector 11, SFB	-56.7 ± 10.0	-120.4 ± 56.0	-63.4 ± 57.4	100
Sector 9, SDA	-14.6 ± 9.9	-118.3 ± 8.3	-103.7 ± 14.1	100

Table 1: Results of measurements of the mean offset of the beam in the SFA magnets with different applied BPM vertical offsets.

BPM offset (µm)	Beam Offset (µm)	Delta (µm)
+125	234.6 ± 10.6	128.7 ± 18.8
+75	167.7 ± 16.5	61.8 ± 22.6
0	105.9 ± 15.5	0
-75	33.1 ± 17.8	-72.8 ± 23.6
-125	-16.1 ± 21.6	-122 ± 26.6

A 100 µm offset was applied to the vertical position on all BPMs, which resulted in the beam being corrected to an orbit that was about 100 µm lower (BPM position and orbit correction errors will mean there is variation of this offset around the ring). The same scan was applied to all magnets and is shown in Figure 3. The new mean offset was found to be 11.4 ± 14.6 µm. The total difference from the first measurement is $-79.3\pm$ 20.4 µm, which agrees quite well with the offset applied. Apart from the 100 µm offset, the pattern of offsets found was generally the same as the previous scan.

A further test using offset beams was done using several different beam offsets and a scanning just one family of sextupoles (for speed). The results are shown in Table 1 and show a very good agreement between the applied BPM offset and the change in beam offset (Delta) measured in the sextupoles. It can be noted that the error of the offset measurements seems to go up as the beam offset from zero is decreased. This is consistent with the gradient of the K_{skew}/K_2 slope decreasing as the beam offset is reduced, thus increasing the error of the gradient fit.

Another way of testing the accuracy of the offset measurement was to mechanically offset individual sextupole magnets by a known amount and then try to measure the offsets in the same way. The sextupole magnets can be raised slightly to allow for thin metal shims to be placed under their bases. Shims were placed underneath three sextupole magnets and a offset scan was redone. The scan for the shimmed magnets in Table 2 show a reasonable correlation between applied and measured offsets. It should be noted that raising the magnet will create a negative offset change as we are measuring the offset of the beam relative to the magnetic centre.

CONCLUSION AND FUTURE PLANS

The vertical offset of the electron beam in all of the sextupoles in the ASLS storage ring has been successfully measured. These measurements have been verified by a number of cross checks and shown to be accurate to within the errors quoted by the gradient fitting.

While all indications are that this is a robust method for determining sextupole offsets, there are several improvements and refinements to the technique that are being investigate. The first obvious refinement would be to speed up the data collection and analysis. The current scans require about 16 response matrix measurements and subsequent analysis using LOCO. The data collection takes about 4-5 hours with a similar amount of time required for analysis. It is hoped that using resonant excitation of the beam and BPM turn-by-turn analysis, combined with an analysis technique that simply measures local coupling, these times can be greatly reduced.

In the meantime, we will be using the results of this analysis to place individual shims on each sextupole magnet. Since almost all magnets are currently sitting too low with respect to the beam, almost all the vertical offsets can be corrected by placing shims under the magnets. The first sectors to be corrected in this way will be the girder 15 to 25, which show the largest offsets.

We hope that with the eventual correction of all of the major vertical sextupole offsets, improvements in coupling correction will follow.

REFERENCES

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