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LOCAL ORBIT RESPONSE MATRIX MEASUREMENT AT SLS

Masamitsu Aiba and Michael Böge, PSI, Villigen, Switzerland

Abstract

The experimental determination of linear optics is essential to achieve a high performance ring accelerator. One of the methods, linear optics from closed orbits, is widely employed to correct linear optics. Due to the ring nature, a quadrupole error at a location of the ring affects the entire orbit response measurement data. The orbit response, however, can be localised to a certain region of the ring when an orbit feedback (or orbit correction) is applied to the rest of the ring. The quadrupole errors located in the region, where the feedback is acting, then have no impact, and the ring optics can be examined locally. An application of this technique to the Swiss light source is discussed.

INTRODUCTION

The experimental determination of linear optics is essential to achieve a high performance ring accelerator. One of the methods, linear optics from closed orbits (LOCO) [1], is widely employed to correct linear optics. The orbit response matrix (ORM) is entered into the LOCO algorithm as an observable. It is the difference of beam positions at the beam position monitors (BPMs) that are measured by changing the corrector excitation currents. Since ORM is determined by the lattice focusing, the ring optics can be corrected by minimising the deviation of ORM from the ideal, model ORM (ORM deviation).

We applied LOCO to the Swiss Light Source (SLS) storage ring [2] and found significant discrepancy in the result as discussed in the next section. This motivated us to develop a method to examine the ring optics locally, i.e. "local orbit response matrix" (LORM) measurement. We present first measurements and our findings.

LOCO AT SLS

The relevant parameters of the SLS storage ring are listed in Table 1 and the result of LOCO correction iteration is shown in Fig. 1.

Table 1: SLS Storage Ring Parameters

Parameter	Value	Unit
Circumference	288	m
Beam energy	2.4	GeV
Number of TBA cells	12	-
Betatron tunes (H/V)	20.43/8.74	-
Number of BPMs/correctors	73/73	-
Number of quadrupoles	177	-

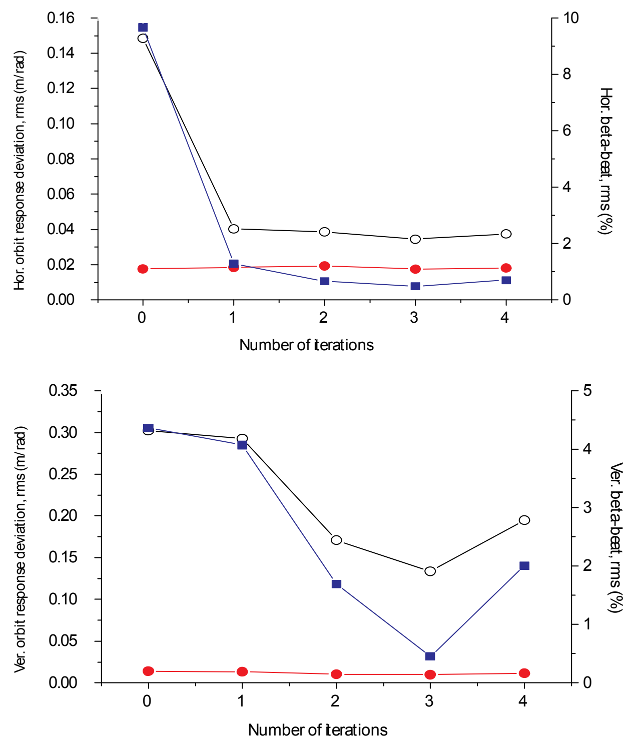

Figure 1: LOCO correction iteration result. The red curve is the ORM deviation after LOCO fit, and the black curve is the ORM deviation after another LOCO fit that excludes the quadrupole strengths from the fitting parameters. The ORM deviation is represented as single rms value over many ORM elements. The blue curve is the beta-beat found from LOCO fit. It is noted that the beta-beat is not found directly from LOCO measurement. Instead, it is inferred from the optics model by applying the quadrupole corrections found from the fit. The noise level (statistical error) of ORM measurement is 0.01 m/rad rms.

Figure 1 was obtained from LOCO optics correction iteration *with the machine*: we measure ORM, compute possible quadrupole corrections, vary the quadrupole excitation currents accordingly and measure again ORM. To compute the quadrupole corrections, the model ORM is fitted to the measured ORM by varying the quadrupole strengths, the corrector calibrations and the BPM calibrations. The coupling terms between the horizontal and vertical planes are not used in this study because the correction of beta functions is main concern. We apply singular value decomposition (SVD) for the fit with appropriate singular value cut (see Ref. [2] for detail).

The ORM deviation after the fit corresponds to the red curve in Fig. 1. We performed another fit at each iteration step with the corrector and BPM calibrations, excluding

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the quadrupole corrections (black curve). After several correction iterations, which remove the quadrupole errors from the machine, the two ORM deviations (red and black plot) should agree within the measurement noise level since all the quadrupole magnets are powered individually, providing a flexible correction capability. The fact that the red plot was always comparable to the noise level is the proof of the correction capability. The application of LOCO did not, however, achieve the agreement especially in the vertical plane as shown in Fig. 1, implying the existence of systematic error(s).

LOCAL ORBIT RESPONSE MATRIX

A part of the ring can be examined by measuring LORM. During the measurement, an orbit feedback is kept running, excluding the BPMs and correctors situated in the region of measurement (RoM) from the feedback loop. Otherwise the LORM is measured as ORM but only for the correctors within RoM. A quadrupole error in a ring varies the ORM elements all around the ring (or at all BPMs) while the LORM elements of RoM are not affected if the quadrupole error is located outside RoM. Therefore the lattice focusing of RoM can be examined independently from the quadrupole errors outside.

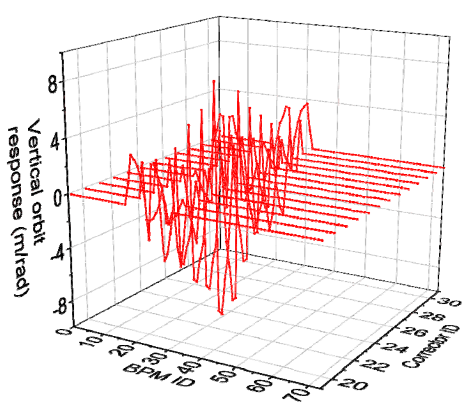

Figure 2: Example of measured LORM. The correctors No. 19−31 are situated in RoM (Sector 3-4 in this example) and used for the measurement.

Figure 2 shows an example of a measured LORM. The LORM elements outside RoM are essentially zero. We established reliable measurement for the vertical plane: the statistical measurement error is about 0.02 m/rad rms, which is comparable to the one for ORM (0.01 m/rad). The statistical error in the horizontal plane is larger than in the vertical plane. This may be because of the beam momentum change due to the measurement corrector excitations as well as the machine drifts. Although a separate beam momentum feedback loop was closed during the measurement and the influence of momentum change was subtracted from the measured LORM (see Fig. 3), there might be residual effect.

RESPONSE MATRIX ANALYSIS

The measured LORM is analysed through several steps:

- ORM is measured before we measure LORM. LOCO fit allows us to find BPM calibrations, i.e. the ratio between the measured beam position and the true beam position. These BPM calibration constants from ORM are applied to correct LORM.
- The orbit shift due to momentum error is removed as discussed in the last section (Fig. 3).
- The strengths of the correctors may slightly differ from measurement to measurement. They are calibrated each time by comparing the measured LORM and the model LORM.
- Finally, the corrected LORM is reconstructed through LOCO fit, taking only the quadrupole corrections of RoM as fitting parameters since the BPMs and correctors have been calibrated in the above steps. Small singular values are cut when less than 0.5% of the maximum one. The cut criterion is adjusted to avoid vigorous quadrupole corrections as well as to achieve a good fit.

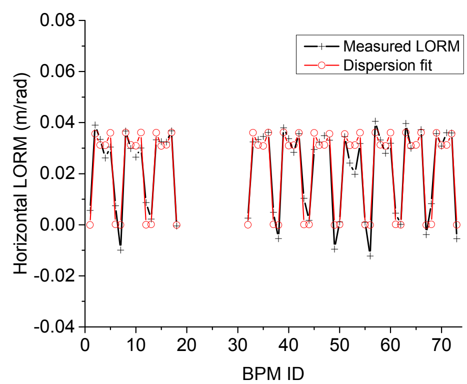

Figure 3: Momentum deviation analysis. The momentum deviation due to the measurement corrector excitation and machine drifts can be extracted from the horizontal LORM. The orbit shift due to the momentum shift can be clearly detected. The data from BPM No. 19−31 are excluded from the analysis since they are in RoM.

So far, we measured LORMs from Sector 2 to Sector 11. RoM is always set to be over two sectors corresponding to two triple-bend-achromat cells out of 12. Table 2 summarises the measurements and analysis.

It is seen that the LOCO fit failed for Sector 4−5 while it was quite successful for Sector 2−3, Sector 6−7 and Sector 10-11. The result for Sector 3−4 was not fully satisfactory. For Sector 4−5, the average quadrupole correction is much larger than in other sectors. The SVD cut value was lowered to 0.2% for Sector 4−5 but no better fit was obtained while the quadrupole corrections get stronger and stronger.

The first measurement of Sector 8-9 showed significant LORM deviation. We discussed this later.

Figure 4 shows the quadrupole corrections found from ORM and LORM measurements as a function of the longitudinal location of the machine.

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Table 2: Summary of LORM measurement and analysis. The second column is the rms LORM deviation from the model, ideal LORM before and after the reconstruction. The last column is the average absolute quadrupole corrections found for the reconstruction.

RoM	LORM deviation, before/after, rms (rad/m)	Quad correction, <|K|> (m-2)
Sector 2-3	0.0207 / 0.0099	0.0020
Sector 3-4	0.0312 / 0.0267	0.0066
Sector 4-5	0.0494 / 0.0439	0.0071
Sector 6-7	0.0264 / 0.0145	0.0044
Sector 8-9*	0.0596 / 0.0438	0.0129
Sector 8-9	0.0383 / 0.0315	0.0066
Sector 10-11	0.0249 / 0.0131	0.0043

* Measurement with orbit bump (see text).

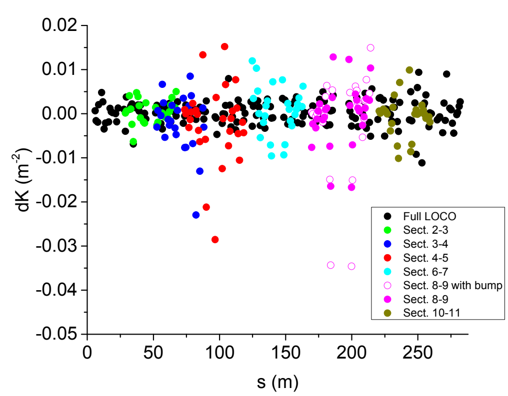

Figure 4: Quadrupole corrections from ORM and LORMs. Black plots are the quadrupole corrections found from ORM, and coloured plots are from LORMs. The absolute (design) quadrupole strengths distribute between ±~2.5 m^{-2}.

DISCUSSION

From the described LORM measurement and analysis, it turned out that LORM of Sector 4−5 cannot be reconstructed. This implies that the part of the machine, Sector 4−5, has a different focusing from the ideal, model optics. The straight section of Sector 5 actually accommodates the so-called Femto beamline [3], where a short chicane and a wiggler modulator are integrated. The optics functions are therefore heavily modified from the regular optics as shown in Fig. 5. These are included in the optics model but it seems that the modelling is not perfect.

The LORM analysis immediately after the first measurement of Sector 8-9 (designated with Sector 8-9* in Table 2) resulted in a similar problem to Sector 4-5, i.e. significant LORM deviation and quadrupole correction. In the straight section of Sector 9, two insertion devices are installed together with an orbit bump to separate the photon beams. It has a vertical edge focusing but it is not included in the optics model since it belongs to the insertion devices. It turned out that the orbit bump was left turned-on during the measurement although we turned off all the insertion devices. We turned off the orbit bump and re-measured Sector 8-9 again. The LORM deviation was then smaller than in the previous measurement (with the orbit bump) by a factor of two.

Sector 4-5 and Sector 8-9 may be, at least partly, the source of the discrepancy in the LOCO optics correction.

The difference between the quadrupole corrections found from ORM and LORM is significant. This is attributed to the fact that LOCO fit minimises the ORM deviation all around the ring. The quadrupoles not only in RoM but also the ones outside vary the ORM elements of BPMs in RoM. Therefore, the quadrupole corrections tend to be distributed over all available knobs. The LORM measurement and analysis, on the other hand, restrict the observables and the correction knobs within RoM. Therefore the method is more sensitive to local focusing errors.

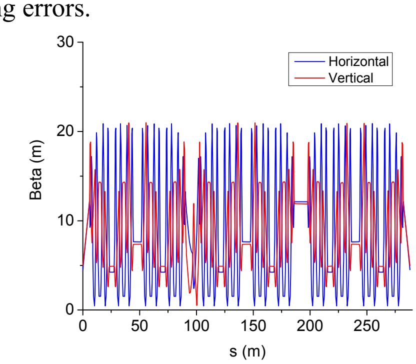

Figure 5: SLS storage ring optics. Sector 5 straight section is around 95 m.

SUMMARY

We have developed a local orbit response matrix (LORM) measurement motivated by the discrepancy observed in the application of LOCO to the SLS storage ring. It turned out, from LORM measurement and analysis, that the measured LORM of Sector 4−5, where the optics is heavily modified, cannot be reconstructed. It also turned out that the orbit bump in the straight section of Sector 9 was left turned-on during the measurements. These may explain, at least partly, the discrepancy observed in the LOCO application.

The method we developed would be of interest for a very large ring that has a large number of BPMs and correctors. The number of elements in ORM is proportional to the number of BPMs times the number of correctors. Therefore the size of ORM may be too large to apply LOCO fit for a large ring. Also, it is always important to apply more than one method to cover the weak points of other methods and possibly to reveal systematic errors.

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