LOCAL ORBIT RESPONSE MATRIX MEASUREMENT AT SLS
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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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>288</td>
<td>m</td>
</tr>
<tr>
<td>Beam energy</td>
<td>2.4</td>
<td>GeV</td>
</tr>
<tr>
<td>Number of TBA cells</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Betatron tunes (H/V)</td>
<td>20.43/8.74</td>
<td>-</td>
</tr>
<tr>
<td>Number of BPMs/correctors</td>
<td>73/73</td>
<td>-</td>
</tr>
<tr>
<td>Number of quadrupoles</td>
<td>177</td>
<td>-</td>
</tr>
</tbody>
</table>

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
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).

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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.
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).

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.

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.

REFERENCES