ANALYSIS OF THE LNLS STORAGE RING OPTICS USING LOCO

X.R.Resende, L.Liu, R.H.A.Farias, M. Plotegher, P.F.Tavares
LNLS, Campinas, SP 13083-970, Brazil.

Abstract

In this paper we discuss preliminary applications of LOCO at the LNLS storage ring. In particular we report on the optics symmetrization performed based on the calibrated model and its impact on beam parameters. We also compare LOCO predictions for the linear optics parameters with independently measured corresponding values.

INTRODUCTION

The synchrotron machine at the Brazilian Synchrotron Light Laboratory (LNLS) is a UVX storage ring for 1.37 GeV electrons composed of six DBA cells whose lengths add up to around 93 meters of circumference. There are 18 horizontal and 24 vertical correctors available in the ring for correcting the orbit as measured at 24 BPMs. In the past, stored beams have been delivered to users which successfully fulfilled demands on stability and size. This has been accomplished by fine tuning the machine using mainly measured response parameters. Existing ring models have had a modest role in giving quantitative answers to questions related to improving the ring performance. The ongoing commissioning of a new EPU beamline, which is expected to become the most demanding one, puts pressure in the direction of improving existing models of the ring optics so that it can be used to improve machine performance. LOCO is a very useful tool to accomplish this [1].

There is also another reason that makes the improvement of the model more appealing now than before. Up to very recently all quadrupoles in the LNLS ring were grouped in families with a single power supply each. In 2008 all quadrupoles were equipped with individual active current shunt circuits [2]. This new feature allows us to trim quadrupole gradients independently and hence the linear optics can be fine-tuned.

RING MODEL AND LOCO FIT

Half the super-period cell of the LNLS UVX lattice is shown in Fig. 1. The other half is just a reflection of the one shown about either end point. There are 12 focusing (QFs) and 12 defocusing (QDs) quadrupoles installed at dispersion-free straight sections - in which elements are odd-numbered - and there are 12 focusing quads (QFCs) at dispersive straights (with even-numbered elements). There are 24 BPMs and 18 horizontal and 24 vertical correctors. Vertical correctors in even straights are installed as additional coils in the QFC quads. One of the vertical correctors in odd straights, labelled ACV03B, is also installed as coils in quads. ACV03B is a doublet corrector, one inside QF03B and another inside QD03B, which are connected in series to the same current supply.

In the LOCO algorithm for the LNLS ring 250 model parameters were typically used in order to fit (2x24) x (18+23) + 2x24 = 2016 measured numbers of the response matrix. There are 2x24 BPM readings for each of (18+23) corrector perturbations and 2x24 readings for the RF frequency perturbation (dispersion function measurement). The corrector ACV03B was not considered for the LOCO fit, as its inclusion would require a modification of LOCO code. As for model parameters, there are 4 for each BPM (gains and H-V crosstalks), 2 for each corrector (kick and roll) and we added the normal and skew strength components of the quadrupoles (72 parameters).

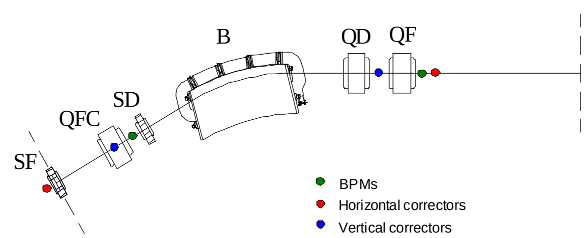

Figure 1: LNLS UVX half super-period cell.

One particularity of the LNLS lattice is that, contrary to most third generation synchrotron sources with very compact lattices, all quadrupoles are flanked by a BPM at one side and by a corrector at the other side. This intercalation of elements with measured data and elements with fit parameters seems to avoid degenerated directions in the search space. As a consequence, the χ^2 minimization algorithm seems less likely to yield non-physical values to the fitted quad strengths. Also, all singular values (Fig. 2) may be included in the fitting.

Although it is possible to store e-beam currents smaller than 100 mA in the LNLS ring with sextupoles off, all experiments reported here were performed with sextupoles on, and chromaticities around zero. Also, measurements were taken with opened insertion devices and at full energy of 1.37 GeV.

At first, a ring model was used in LOCO with nominal positions for all its elements. Since its commissioning in 1997, many interventions have occurred in the ring that changed the precise locations of these elements. BPMs, for example, have been shifted up to a few centimeters. A new position survey was done and the collected data implemented in the model. This has improved χ^2 considerably and the fluctuation of the quadrupole gradients, as given by the LOCO fitting, has fallen from a few percent down to expected values below 1%.

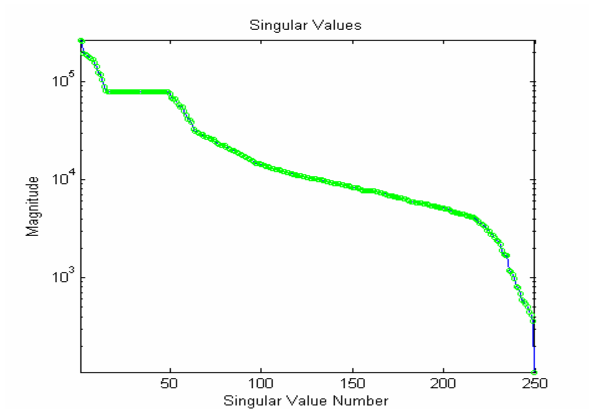

Figure 2: LOCO singular value spectrum for the coupled response matrix fit.

RING SYMMETRIZATION

One of the most useful applications of LOCO is certainly the symmetrization of beam optics based on its calibrated models [3]. We used LOCO in order to minimize beta-beating as given from the model beta functions within each group of equivalent quadrupoles. At each iteration of LOCO we measured the response matrix, run LOCO and calculated the change of excitation currents for the quadrupoles in order to bring their focusing strengths equal to the group average value. These current changes are then implemented in the machine using individual shunts and power supplies of the families. By implementing the average change within each quad family using the family power supply we minimized the currents left for the shunts, which are limited to ±5A. This process is iterated repeatedly until convergence is achieved.

Model Validation

We first proceed with a model validation test before symmetrization. We performed only one iteration of the algorithm and measured beta functions independently for comparison. This measurement was based on tune shifts due to variations of quadrupole strengths using the power supply shunts. Results show that, although there are discrepancies between measurements and LOCO predictions, the model is able to capture the overall asymmetry in the ring (Fig.1). Before symmetrization (iteration #0), measured horizontal and vertical average beta-beat (standard deviation of beta values at the quads divided by their average value) were 11.4% and 16.6%, respectively. After one iteration these numbers dropped down to 8.3% and 7.2%. The corresponding numbers extracted from the LOCO model were somewhat lower: 2.5% and 1.5%. The residual asymmetry in the model comes mainly from beta functions at focusing quadrupoles (QFCs) located at dispersive straights. This is consistent with the fact that, in the model, we did not include effective quad gradients for the sextupoles which are adjacent to those QFCs, and in which there may be a small residual dislocation between magnetic center and beam closed orbit left from the determination of a golden orbit carried out using the Beam-based calibration technique [4].

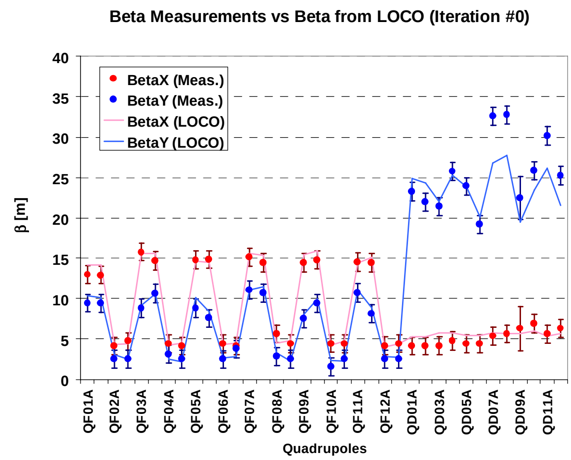

Figure 3: Comparison between measured beta functions and beta functions from LOCO-calibrated ring model.

Convergence

The symmetrization algorithm converges very fast. In the LNLS case, most of the symmetrization allowed by the limited model occurs at the first iteration (Tab.1). As mentioned previously, the model shows a significant residual beta-beat in the QFCs. Another result worth of mention is that, although the model beta-beat was reduced to less than 1% for QFs and QDs, the corresponding measured values are higher. This discrepancy indicates that a further refinement of the model is desirable. Despite these limitations, the symmetrization worked well, reducing the average beta-beat to around half its initial size.

Table 1: Beta-beat [%] reduction as a function of iteration number. (**0-M** and **3-M** correspond to **measured values**)

Iter. #	β_x **(Fs)**	β_y **(Fs)**	β_x **(Ds)**	β_y **(Ds)**	β_x **(FCs)**	β_y **(FCs)**
0-M	6±1	13±1	19±1	17±1	9±1	19±1
0	4.0	10.3	3.9	10.0	5.3	13.0
1	0.5	0.6	0.4	0.6	3.2	6.6
2	0.4	0.6	0.2	0.3	3.1	6.6
3	0.2	0.3	0.2	0.3	3.1	6.4
3-M	3±1	4±1	15±1	10±1	7±1	7±1

Tunes, Beta and Dispersion Functions

For the final symmetrized optics, we measured horizontal and vertical tunes of 5.2273 and 4.1405, respectively, and obtained 5.2296 and 4.1402 independently from the LOCO fit. Experimental and fitted vertical tunes agree within experimental error, which is ±0.0006. The fitted horizontal tune, on the other hand, is slightly off the measured value. This result, again, seems to be consistent with the interpretation that the discrepancy comes from horizontal closed orbit displacement at the sextupoles.

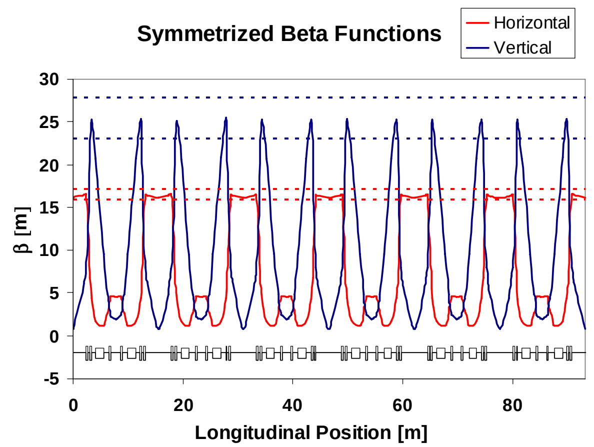

Figure 4: Beta functions for the symmetrized optics as determined from orbit response matrix measurements. Dashed lines show intervals within which lied maxima of the original beta functions.

The R.M.S. value of the horizontal dispersion function at the dispersion-free straights has been reduced from 3.8 to 0.5 cm. On the other hand, the symmetrization did not reduce the vertical dispersion function below its 0.9 cm R.M.S figure. These results can be visualized in Fig.5. Measured and modelled dispersion functions agree at the micrometer level.

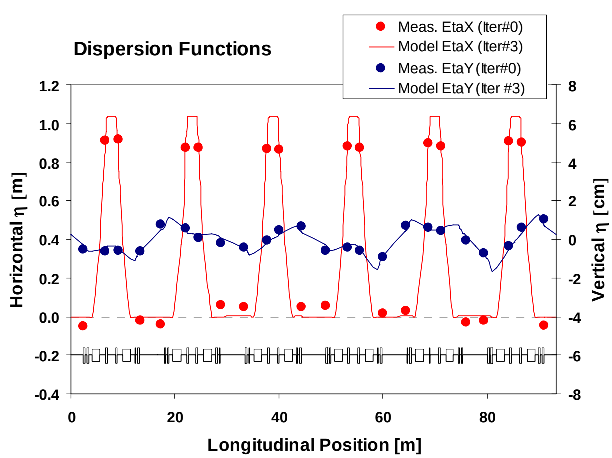

Figure 5: Comparison of measured dispersion functions (symbols) before symmetrization with corresponding functions given by the model after symmetrization (lines).

Impact on Beam Parameters

We looked for beneficial effects of the optics symmetrization on various beam parameters. In particular we measured beam lifetime and transverse coupling before and after symmetrization. The lifetime increased approximately one hour with the symmetrized optics (Fig. 6). No global coupling reduction could be observed in X-ray pinhole image measurements. The beam image tilt angle, nevertheless, showed a systematic increase, indicating that the symmetrization might have changed the coupling locally through modification of phase advances.

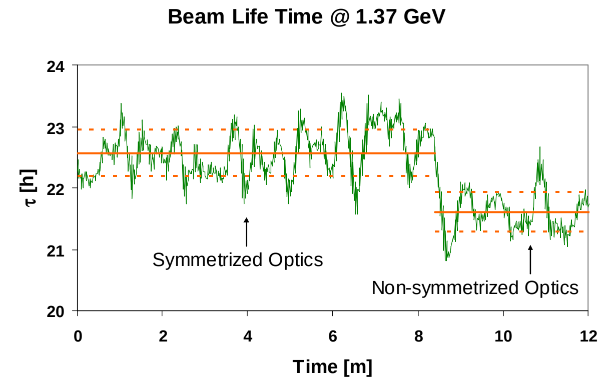

Figure 6: Improvement of beam lifetime with symmetrization.

CONCLUSIONS AND PERSPECTIVES

We have tested the model and the LOCO algorithm for the LNLS ring. Although there are clear discrepancies between predicted and measured optics parameters, the LOCO-calibrated model has been improved to the point where symmetrization of the ring based on its predictions was possible. Beta-beat was then reduced to half its original value with an accompanying increase in one hour of beam lifetime.

We are currently considering the use of LOCO as a diagnostic tool by the operation group for identifying undesirable eventual changes in the machine. For that purpose, a GUI has been written in Matlab that automates the LOCO analysis. In addition, we are studying how to best include and correct the effects of insertion devices and sextupoles in the calibrated model.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the indispensable and prompt help of G. Portmann in the process of learning how to use LOCO and in the initial setting of the configuration electronic files.

REFERENCES

[1] LOCO, Beam Dynamics Newsletter 44, ICFA, December 2007.
[2] C. Rodrigues, A.R. Silva, "Active Shunts for the LNLS Storage Ring Quadrupoles", PAC2007.
[3] A. D. Robin, J. Safranek, and W. Decking, Phys. Rev. ST Accel. Beams 2, 044001.
[4] L. Liu *et al*, "Beam Based Calibration of the LNLS UVX Storage Ring BPMS", these proceedings.