

# LOCO APPLICATION TO NSLS2 STORAGE RING DISPERSION AND BETA BEATING CORRECTION

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## Abstract

During the short run in early July, 2014, we made changes to the setup of Matlab Linear Optics from Closed Orbits (LOCO) for NSLS-II and applied it successfully to the linear optics correction. The Matlab middle layer (MML) setup was also verified with Input-Output tests for all quadrupole families. The LOCO setup was further tested with an intentional quadrupole error. After the successful LOCO correction, the RMS beta beating was reduced from the initial value of 5.5% to 1.9% in x, and 5.6% to 1.0% in y. The RMS horizontal dispersion error was reduced from 21 mm to 6 mm. It is critical to keep the same closed orbit for LOCO correction. Because some correctors were nearly saturated at the time, closed orbit couldn't be controlled for additional iterations. We expect LOCO to achieve better optics correction after the orbit control is improved.

## INTRODUCTION

LOCO has been a powerful beam-based diagnostics and optics control method for storage rings and synchrotrons worldwide ever since it was established at NSLS by J. Safranek [1]. This method measures the orbit response matrix and optionally the dispersion function of the machine. The data are then fitted to a lattice model by adjusting parameters such as quadrupole and skew quadrupole strengths in the model, BPM gains and rolls, corrector gains and rolls of the measurement system. Any abnormality of the machine that affects the machine optics can then be identified. The resulting lattice model is equivalent to the real machine lattice as seen by the BPMs. Since there are more than five BPMs per betatron period in NSLS2 storage ring, the model is a very accurate representation of the real machine. According to the fitting result, one can correct the machine lattice to the design lattice by changing the quadrupole and skew quadrupole strengths. LOCO is so important that it is routinely performed at many electron storage rings to guarantee machine performance, especially after the Matlab-based LOCO code [2] became available. The Matlab version includes a user-friendly interface, with many useful fitting and analysis options.

## MATLAB LOCO CODE IMPROVEMENT

Full Jacobian (J) calculation takes four hours for NSLS2 storage ring compared to five minutes linear J in a standard laptop. Besides, J doesn't change significantly

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when the solution is close to the global minimum. Therefore, a selection between calculating a new or reusing an existing J at every LOCO iteration has been implemented in "loco.m". The standard size of J for NSLS2 storage ring (SR) is ~130k·2k. Singular Value Decomposing (SVD) JTJ (~2k·2k) instead of J for all fitting methods is implemented to speed up the SVD calculation. Using the Optimized weights for all fit parameters minimizes the changes of quadrupole gradients while at the same keeping the good fitting result. Reducing quadrupole families and grouping neighbouring quadrupoles in the fitting are introduced to cure the degeneracy problem caused by the coupling between fit parameters. Five families, QL1, QL2, QH1, QH2, and QM2, instead of all eight families, QL1, QL2, QL3, QH1, QH2, QH3, QM1, and QM2, are used in the LOCO fitting. Also, two QM2 quadrupoles at the same cell are grouped together. All these new features have been tested before updating the relevant codes.

## CRITICAL ISSUES BEING EXAMINED

The following lists the most important steps that one has to check before LOCO application:

1. LOCO connection to machine  
Matlab middle layer (MML) mapping between hardware and channel access in the control system has been examined for all the quadrupoles, sextupoles, correctors, and BPMs. They are in good agreement.  
MatLab codes that generate LOCO files and implement optics correction have been checked and no error is found.
2. Quadrupole saturation  
 $\Delta K/K = \Delta I/I$  is not accurate. As an example of QM2 quadrupoles, at the operational current ~140A,  $K/I=1.2 \cdot \Delta K/\Delta I$ , as shown in Figure 1.  
Our solutions are: iterate several times; use unit conversion, amp2k.m and k2amp.m, based on measured magnet excitation curves in MML for  $\Delta I$  [3].
3. Quadrupole hysteresis  
Cycle magnets after optics corrections are applied.
4. BPMs not reproducible  
Use constant current and filling pattern
5. Orbit control  
The tolerance on orbit reproducibility has to be well understood and setup properly.

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As an example, 0.5mm orbit error in one of SM2 sextupoles is equivalent to 1% quadrupole gradient error in one of QH1 quadrupoles. Also, NSLS2 storage ring is highly nonlinear, the contribution to beta beat via the orbit error is crucial for setting up the orbit tolerance. Therefore, we did simulations which are summarized in Table 1.

The conclusions are: ~0.5mm orbit error induces 1-2% beta beating in both x and y dimensions; we have to save the present orbit as “Golden orbit” and maintain it better than 100µm level before and after applying optics correction.

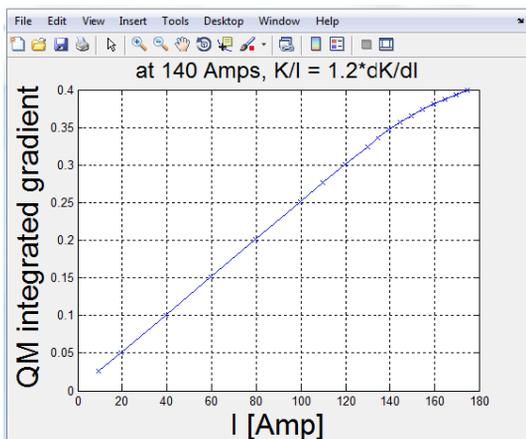


Figure 1: QM2 quadrupole integrated gradient vs current.

Table 1: Simulation Study of Orbit Error vs. Beta Beating

Corrector pair	Corrector setting x/y (A)	RMS orbit error x/y (mm)	Beta beating x/y (%)
Cell(30,1)	0.5/0.5	0.23/0.18	0.13/0.38
Cell(30,1)	1.5/1.5	0.71/0.55	1.63/1.30
Cell(30,3)	1.5/1.5	0.32/0.72	1.70/1.10

### SIMPLE TEST WITH AN INTENTIONAL QUADRUPOLE ERROR

Vary one or a couple of quadrupoles, and check that the predicted correction works:

Measure LOCO data; after increasing quadrupole QM2(30,1) with 2A, measure LOCO data again. After fitting the two different data sets, LOCO found the error quadrupole, the one with red circle, but there exists cross talk between fit parameters QM2(30) and QM2(29), as shown in Figure 2.

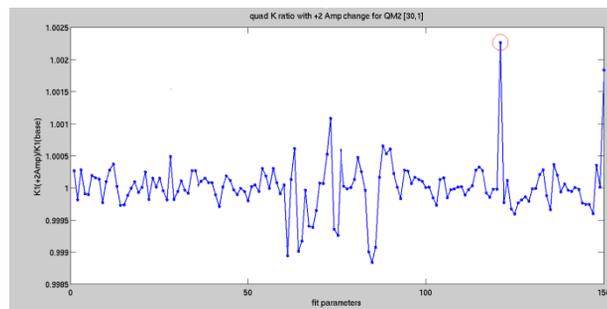


Figure 2:  $K1(+2Amp)/K1(base)$  vs fit parameter index. Fit parameter indexes 1-30, 31-60, 61-90, 91-120, and 121-150 are for QL1, QL2, QH1, QH2, and QM2 respectively. The lattice starts from cell 30, cell 1, cell 2, finally to cell 29. Two quadrupoles QM2 in the same cell are grouped together.

### LOCO APPLICATION FOR DISPERSION AND BETA BEATING CORRECTION

- Detail description of the LOCO measurement:  
 We saved the corrected orbit as “Golden Orbit” before LOCO measurement. Comparing the LOCO fit result between using 60 correctors per plane and using all the 180 correctors per plane,  $\chi^2$  reduction and beta beating after the same number of iterations are identical, we decided to use 60 correctors to make the measurement 3 times faster. Besides using the constrained fitting method, we chose five families, QL1, QL2, QH1, QH2, and QM2, instead of eight families in the fit parameters to further cure the degeneracy problem caused by the coupling between fit parameters. Two QM2 quadrupoles in the same cell are grouped together. Every time after applying LOCO correction, we corrected the orbit back to “Golden Orbit” within 10 µm residual orbit error. Unfortunately, after 2 iterations, we ran out of horizontal corrector strength to keep the residual orbit error within the tolerance.
- The followings are the result of the LOCO study:

1. Beta beating before LOCO correction

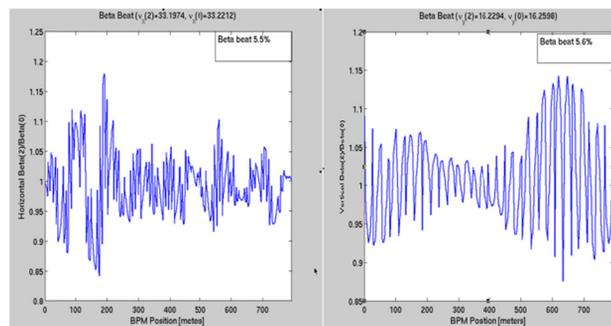


Figure 3: Beta beating vs BPM position, x (left) and y (right). RMS beta beatings are 5.5% in x and 5.6% in y respectively.

## 2. Dispersion before LOCO correction

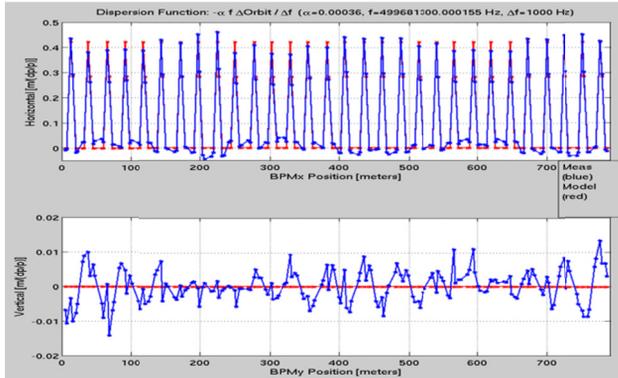


Figure 4: Dispersion vs BPM position, x (top) and y (bottom). Blue and red curves are the measured and designed dispersions respectively.

## 3. Beta beating after LOCO correction

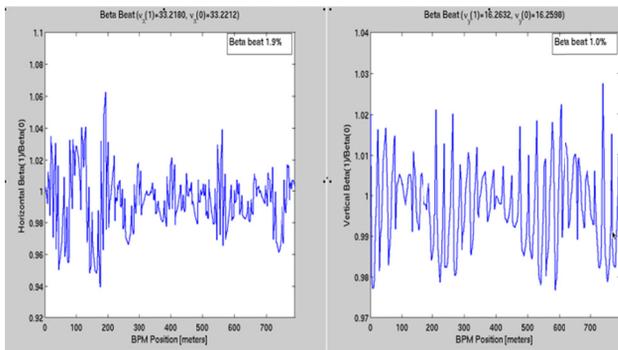


Figure 5: Beta beating vs BPM position, x (left) and y (right) after applying LOCO correction. RMS beta beatings are 1.9% in x and 1.0% in y respectively.

## 4. Dispersion after LOCO correction

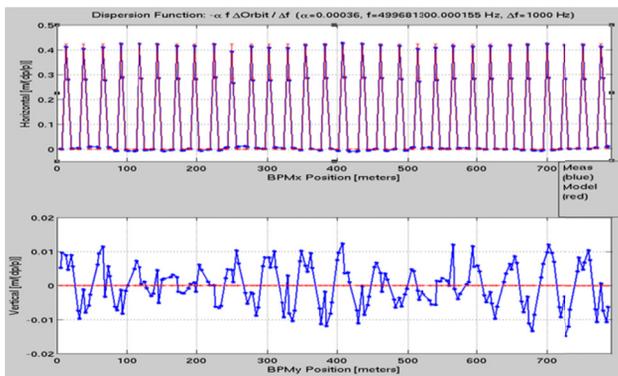


Figure 6: Dispersion vs BPM position after applying LOCO correction, x (top) and y (bottom). Blue and red curves are the measured and designed dispersions respectively.

## 5. Dispersion error before and after LOCO correction

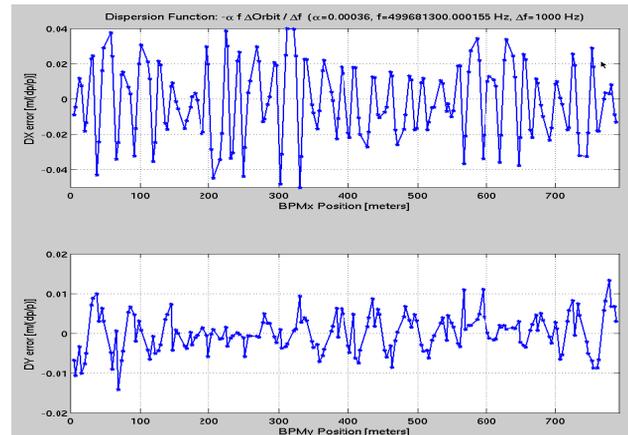


Figure 7: Dispersion error vs BPM position before applying LOCO correction, x (top) and y (bottom). RMS dispersion errors are 21mm in x and 5mm in y respectively.

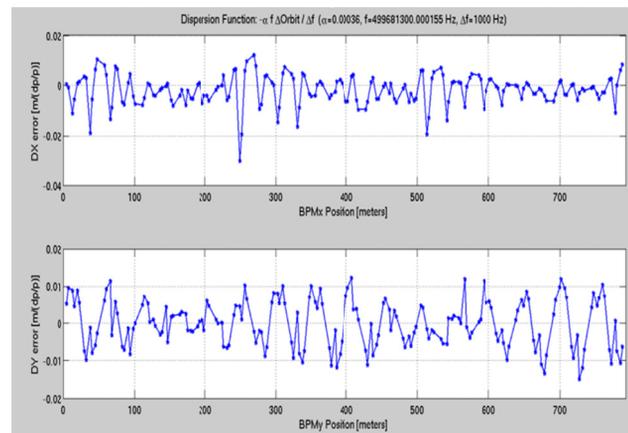


Figure 8: Dispersion error vs BPM position after applying LOCO correction, x (top) and y (bottom). RMS dispersion errors are 6mm in x and 6mm in y respectively.

## CONCLUSIONS

Critical step is to set up “Golden Orbit” which is reproducible to  $\mu\text{m}$  level, before and after applying optics correction. Beta beatings were corrected down to 1.9% in x and 1% in y; afterwards, we ran out of corrector strengths to keep “Golden Orbit” within the tolerance. After the correction, dispersion is close to the design value. LOCO simulation study indicates:  $\sim 0.5\text{mm}$  RMS orbit deviation induces 1-2% beta beating in x and y; Beta beating correction depends on the errors of beam based alignment (BBA) data and also the reproducibility of orbit.

## REFERENCES

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