

USE OF LOCO AT SYNCHROTRON SOLEIL

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Abstract

SOLEIL is a 354 m long third generation light source located South of Paris (France). In this paper, the first attempts using LOCO is described together with problems encountered due to the storage ring lattice compactness. The introduction into the code of constraints on the quadrupole gradient variations gives tremendous improvements. The convergence is satisfactory, beta-beatings are reduced from 5 to 0.3% RMS in both planes. Restoring the symmetry of the lattice enhanced the performance of the storage ring. In the last part, different ways of using LOCO as a powerful diagnostics tool are given.

INTRODUCTION AND TOOLS

SOLEIL is 2.75 GeV third generation synchrotron light source delivering photons to users since January 2007. The storage ring is based on a modified Chasman-Green optics with distributed horizontal dispersion all around the ring reaching a 3.73 nm.rad H-emittance [1]. The strong focusing optics is the result of the very compact machine accommodating 10 individually powered quadrupole magnets (Q-magnets) in each of the 16 cells. A sketch of the optical functions is given by figure 1.

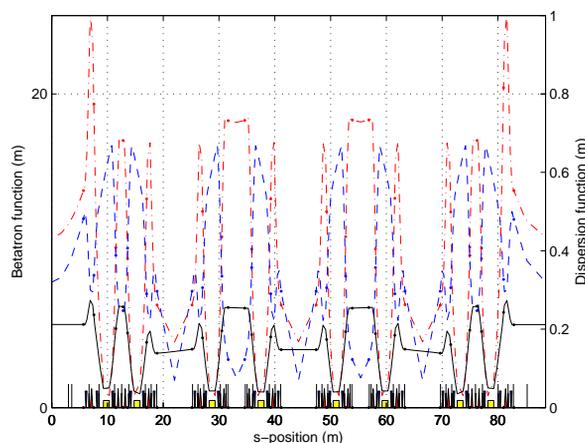


Figure 1: Optical functions for one super-period of the SOLEIL storage ring lattice: horizontal (red) and vertical (blue) beta functions, and horizontal dispersion function (black solid line).

Since the beam transverse dynamics is very sensitive to quadrupole errors, any beta-beating can jeopardize the global performance of the storage ring by inducing resonance excitations leading to reductions of the on- and off-momentum apertures, hence of injection efficiency and e-beam Touschek life-time [2].

Despite the carefully construction of Q-magnets, the high quality of the magnetic measurements, and their precise alignment on the girders altogether into the storage ring (below 60 μm RMS [3]), the 4-fold symmetry of the lattice cannot be rigorously preserved, as shown by figure 2 where the H-dispersion function is displayed before any attempt of restoring the lattice symmetry.

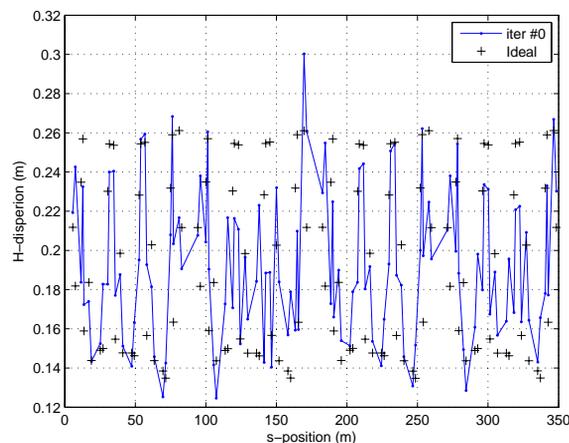


Figure 2: Horizontal dispersion function for the SOLEIL storage ring lattice: measurement before symmetrization (blue solid line) and ideal lattice (black crosses).

A standard tool for restoring the linear optics is the so-called LOCO code (*Linear Optics from Closed Orbits*, for details about the method and the code, the reader is referred to [4] and references therein). The Matlab version of the code [5] is used at SOLEIL together with the Accelerator Toolbox [6] and the Matlab Middle Layer [7, 8].

Measuring a matrix response using 120 Beam Position Monitors (BPMs) and 56 steerer magnets in both planes takes typically 25 min at SOLEIL. Beam noise measured at a 2 Hz acquisition rate is 220 nm RMS and 60 nm RMS respectively in horizontal and vertical planes. A total of 896 parameters are used in the fitting procedure for the full coupled orbit response matrix (see Tab. 1).

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Table 1: Fitting parameters used in LOCO code for restoring the SOLEIL lattice symmetry.

Parameter types	Number of elements
Quadrupole gradients	160
BPM gains	240
BPM H-V and V-H coupling	240
Steerer calibrations	112
Steerer rolls	112
Skew quadrupole strengths	32

APPLICATION OF LOCO

First Attempts

First results of LOCO were very much puzzling since the solutions gave too large variations of the quadrupole gradients: from 0.5% up to 6%. According to the magnetic measurements a 0.1% RMS gradient identity was expected. Moreover all power supplies had been individually calibrated with respect to the same reference DCCT. In addition to these unrealistic Q-magnet variations, the choice for selecting the right number of singular values in the SVD minimization was not satisfactory either. No clear cut in the singular value spectrum was showing up (see Fig. 3), so that the number of values to be kept was obtained by try and error. Too large number of values led to more than 10% relative gradient variations, too small number to inefficient solutions. It is worth noting that for each of the choices of singular value number, the symmetry of the betatron functions could be restored, even if the resulting gradient distribution was very different. This not uniqueness of the solution is not fully surprising since LOCO is essentially fitting the betatron functions at the location of BPMs.

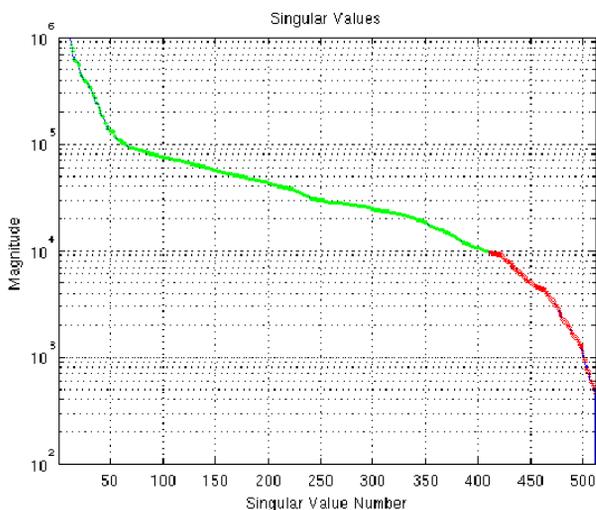


Figure 3: Singular value spectrum for the uncoupled orbit response matrix.

Additional Constraints and new Results

It turned out that the main reason for these large quadrupole variations was related to the high compactness of the storage ring lattice. With 10 quadrupole magnets and only 7 to 8 BPMs per cell, the code encountered difficulties to distinguish the effect of neighboring Q-magnets not having a BPM in between. This issue seems to be common for most of the latest strong focusing modern facilities (Diamond, SSRF, Canadian, Australia light sources). A solution proposed by SPEAR3 people consists in adding a constraint on the Q-magnet variation using a penalty function [9].

In practice, the effects are dramatic at SOLEIL. The code converges very fast (3 iterations) to a solution with Q-magnet gradient variations only up to 1.2% peak. Figure 3 displays the total individual Q-magnet gradient variations, sorted by families, after 3 successive iterations of the code. Beta-beatings are reduced from 5% down to 0.3% RMS in both planes (Fig. 4). Another good point is that all singular values can be used during the fitting procedure.

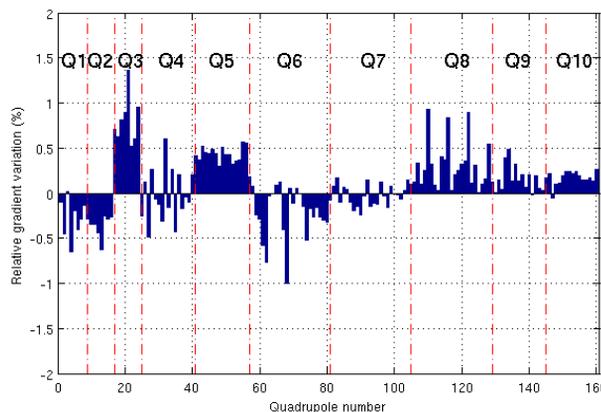


Figure 4: Total relative variations of the Q-magnet gradients after two iterations of the LOCO code. The 160 quadrupoles are sorted into 10 families (Q1 to Q10).

BPM gains are found to be identical within 1% to 2%, which is satisfactory since during their installation, the button electrodes have been carefully sorted based on their capacitance values. Moreover all the BPM cables had been matched in order to get the same attenuation factors.

These results have enabled to reduce resonance widths and to improve the injection efficiency especially when Apple II insertion devices are closed to their minimum gaps of 15.5 mm.

Concerning fitting the off-diagonal terms, it has been shown that, the global coupling can be reduced from 0.3% to 0.08% (experimentally measured using the pinhole camera).

Moreover as the BPM electronics suffers from strong coupling of the input RF channels from horizontal to vertical plane, LOCO output are in good agreement with measurements done on the diagnostics bench. Coupling values range up to 5% (see comparisons on Fig. 6).

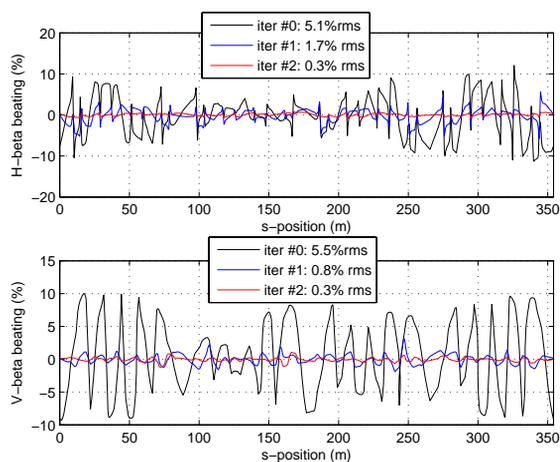


Figure 5: Beta-beating reduction: before applying LOCO results (black), after one (blue) and two (red) iterations of the code.

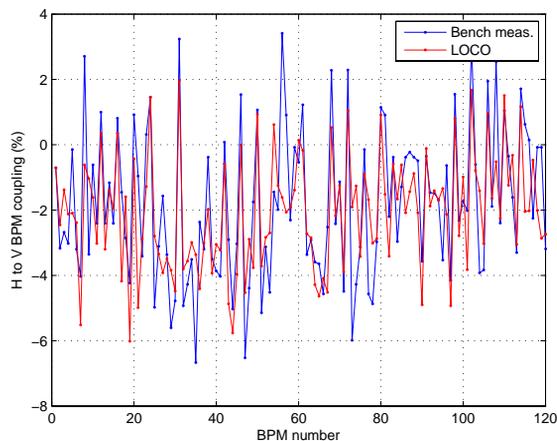


Figure 6: Horizontal to vertical BPM coupling values: comparison between data from LOCO (red) and direct measurements (blue) on diagnostics bench.

OTHER USES OF LOCO FOR DAILY OPERATION

The use of LOCO does not reduce only to restoring the lattice symmetry. LOCO is very suitable and valuable to quickly identify problems with equipments. At SOLEIL acquiring a full set of data (orbit response matrix, dispersion functions and e-beam noise) takes only 30 min. After each shutdown period, a carefully analysis of these data is performed using the LOCO code.

During maintenance and installation of new components into the storage ring, parts of the 120 BPMs and 56 steerer magnets are often disconnected. Even with right labeling of the cables, re-cabling errors may occur from time to time. A look to the measured orbit response enables to quickly identify the errors and to correct for them.

Last year, four BPMs have been identified having the wrong longitudinal position in the lattice with respect to their real location in the storage ring. This mismatch of only a few centimeters was showing up very clearly when analyzing the LOCO results.

Similarly loose connection of the cables of the steerers (secondary coils in the sextupole magnets) are quickly identified.

On the long term, LOCO can also be used for surveying the deterioration of the ring symmetry on a month to month basis.

CONCLUSION

With the modified version of the LOCO code, including constraints on the variations of the Q-magnet gradients, it has been possible to restore the storage ring symmetry to a 0.3% RMS level in both planes and with gradient variation compatible with the results of the magnetic measurements.

With respect to dynamics, the next step is to correct beta-beating from insertion devices.

In parallel a reflection is on going concerning the use of LOCO software directly by the operation group.

ACKNOWLEDGEMENTS

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