CLOSED ORBIT CORRECTION AT THE LNLS UVX STORAGE RING

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Abstract

Global orbit correction in the LNLS storage ring using SVD algorithms often takes a few correction iterations to converge to the smallest distortion around the machine. This happens even when an experimentally determined response matrix is used in the SVD calculations of the corresponding correction matrix. In this report we study the possible causes for this effect, including the non-linear dependence of the measured orbit response matrix on the corrector kick strength, non-linear BPM response, corrector magnet hysteresis, non-linearity of the optics due to the presence of sextupoles and coupling between the transverse planes.

INTRODUCTION

The stability of the photon beam position in a synchrotron radiation source is a very important performance parameter. At the Brazilian Synchrotron Light Source (LNLS) we have set up a task force to improve the beam orbit stability. The task force has the general purpose of minimizing/suppressing long and short period beam instability sources and improving the orbit measurement and correction system. The study presented in this report is part of the efforts of this task force and is motivated by the observation that one needs a few correction iterations to arrive to the smallest orbit distortion in the UVX storage ring. The number of iterations needed depends on the initial distortion but as many as 5 or 6 iterations are sometimes applied by the feedback system in a user's run when the orbit is suddenly distorted by some tens of micrometers by some undesirable phenomenon. We have also observed that applying the full calculated correction often 'overcorrects' the orbit, even when the measured response matrix is used. To avoid this, the orbit correction software allows the actual implementation of only a fraction of the calculated correction. Currently this fraction is set to 60% for normal users operation.

On the other hand, some user experiments at LNLS are becoming more demanding and require position stability of the electron beam of a few microns, a value smaller than the usual specification of 10% of the beam size (which at the LNLS machine varies from 2 (35) micrometers to 9 (120) micrometers in the vertical (horizontal) plane, depending on the source point). Furthermore, a new high-resolution undulator beam line will soon be in operation and will also require a high level of position stabilization. Besides that, this new beam line will introduce the additional difficulty of maintaining orbit stability while the insertion device is in movement.

These new circumstances motivated a careful analysis of even small particularities that may contribute to the effectiveness of the orbit feedback system. We analysed the dependence of the measured orbit response matrix on the corrector kick amplitudes, the coupling between transverse planes, the dependence of the response matrix elements on the magnetic history of the correctors and the non-linearity in the optics due to the presence of sextupoles. All these effects can contribute to slow down convergence of orbit correction. Here we report on our attempts to identify the contribution of each one of these effects in the case of the LNLS UVX storage ring.

ORBIT RESPONSE MATRIX MEASUREMENTS

The orbit response matrix $\mathbf{R}$ is measured by exciting corrector kick angle variations $\boldsymbol{\theta}$ and recording the corresponding orbit variations $\mathbf{u}$ at BPM locations,

$$\mathbf{u} = \mathbf{R}\,\boldsymbol{\theta} \qquad (1)$$

The simple relation above requires, however, attention to some particularities during the response matrix measurement. When performing an actual measurement, the control system response times must be taken into account so that orbit data before and after the kick is applied is correctly identified. The LNLS control system updates variable readings every ≈ 200 ms and the BPM readings are not synchronized. Besides care with orbit acquisition timing, we have also implemented a cycling procedure for the correctors in order to standardize their magnetic histories before the measurement. This is important particularly in comparing results from different measurements. The magnitude of the kick must also be optimized based on the best compromise between a large signal to noise ratio in orbit measurement and the advantage of staying in the machine linear region.

At LNLS we have achieved orbit response matrix measurement repeatability of 0.02 mm/mrad.

DEPENDENCE OF THE MEASURED RESPONSE MATRIX ON THE CORRECTOR KICKS

The orbit response matrix measurements at the UVX electron storage ring revealed a dependence of the matrix elements on the corrector kick strengths.

To investigate the contribution of different magnetic histories of the correctors, we compare a series of 5 successive measurements with the same parameters, without the initial corrector cycling procedure. Some results are shown in Figure 1. There are differences of 0.03 mm/mrad between the various measurements.

To study the dependence on the kick amplitude, the corrector was cycled before the measurement. Figure 2 shows a variation of up to 0.5 mm/mrad in the matrix elements corresponding to a variation from -0.05 to +0.3 mrad of the ACV03A vertical corrector kick. The curves in Figure 2 show a monotonic tendency, i.e., are not noisy fluctuations. The behaviour is probably due to a combination of non-linear effects from the electromagnetic correctors, the BPMs and the accelerator optics.

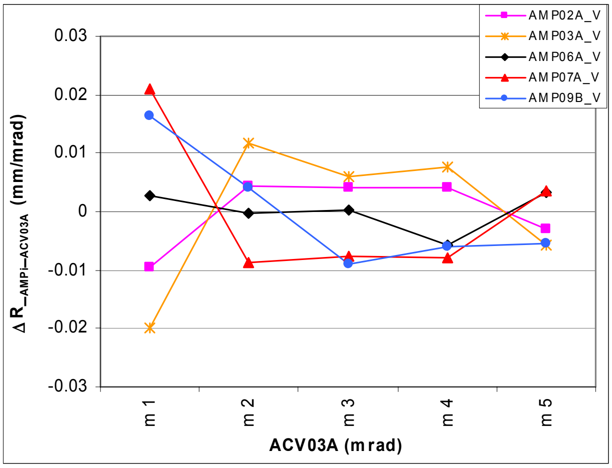

Figure 1: Variation of orbit response matrix elements on the magnetic history of the ACV03A vertical corrector. The horizontal axis represents successive measurements of the response matrix without any standardization procedure for the correctors.

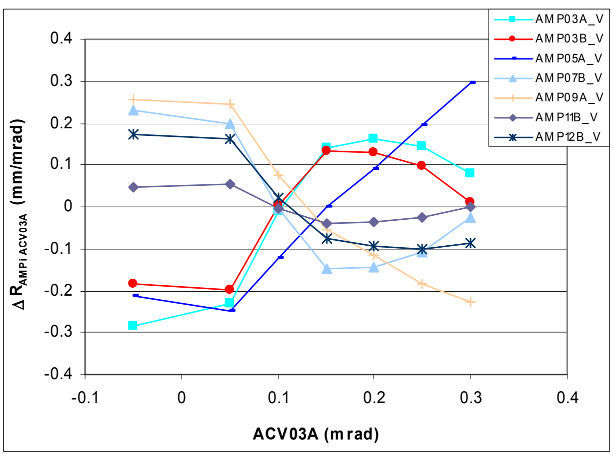

Figure 2: Orbit response matrix elements measured as a function of the ACV03A vertical corrector kick strength used in the measurement. The various curves correspond to different BPMs.

COUPLING

Coupling between horizontal and vertical planes affecting orbit correction can be caused not only by skew components of the magnets but also by alignment errors of correctors and beam position monitors. Applying a horizontal orbit correction can introduce a distortion on the otherwise perfectly corrected vertical orbit, for example, if the horizontal correctors are misaligned (rotated). Depending on the degree of coupling, a minor vertical correction will be needed and so on. The coupling effect can be included in the correction algorithm if we extend equation (1) to the coupled case:

$\mathbf{u} = (\mathbf{x}, \mathbf{y})$ and $\boldsymbol{\theta} = (\boldsymbol{\theta}x, \boldsymbol{\theta}y)$.

The response matrix **R** will have off-diagonal terms describing coupling conditions.

Figure 3 shows the measured coupled response matrix terms for the LNLS UVX storage ring.

The usual SVD method can be applied to the coupled equation resulting in simultaneous corrections for the horizontal and vertical orbits.

However, during simulations of correction with coupling in the LNLS ring, a problem of having-more-equations-than-variables appeared. In this ring the number of monitors equals the number of correctors for the vertical plane but surpasses the number of correctors for the horizontal plane. This means that the vertical orbit can in principle be corrected exactly at the position monitors in the decoupled situation but the horizontal orbit distortion can only be reduced in the least squares sense. The exact vertical orbit correction at BPMs in the LNLS ring is considered to be the ideal situation for users. When the coupled response matrix is used, the vertical orbit also becomes reduced in the least squares sense, since the total number of correctors is less than the total number of position monitors. This problem can in principle be overcome by applying the eigenvector method with constraints [1], where the condition of exact vertical correction at all monitors can be applied.

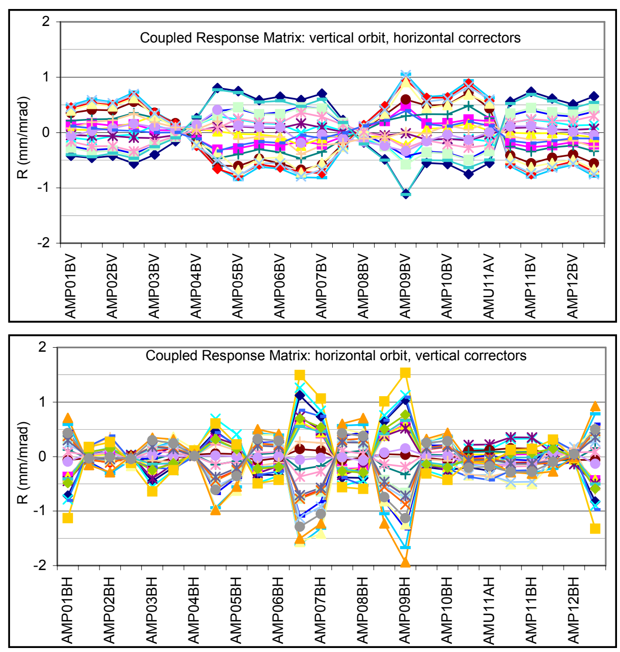

Figure 3: Measured coupled terms in the orbit response matrix. The top and bottom graphs show the vertical orbit variation induced by horizontal correctors and vice-versa.

We have simulated orbit correction using three different algorithms: a) using the uncoupled response matrix, b) using the coupled response matrix and c) using the coupled response matrix with constraint conditions of exact vertical correction. The two former methods use the SVD algorithm to produce an orbit correction matrix and the third method use the technique described in ref [1], where the constraint conditions are introduced using

Lagrange's method of indeterminate multipliers. To compare the three methods experimentally, a correction matrix is generated for each method and the same distorted orbit is produced by exciting some correctors with the same kick variations used for response matrix measurements. This trick is used to try to isolate non-linear from coupling effects. The idea is that in this way the necessary kick for orbit correction will be almost the same as the one used for response matrix measurement.

Figure 4 shows the rms value of the residual orbit after just one correction iteration for each method. We see that when coupling is included, the rms value of the residual orbit is a factor of 3 smaller than in the uncoupled case. In contrast, the effect of including the constraints or not is smaller than other experimental features.

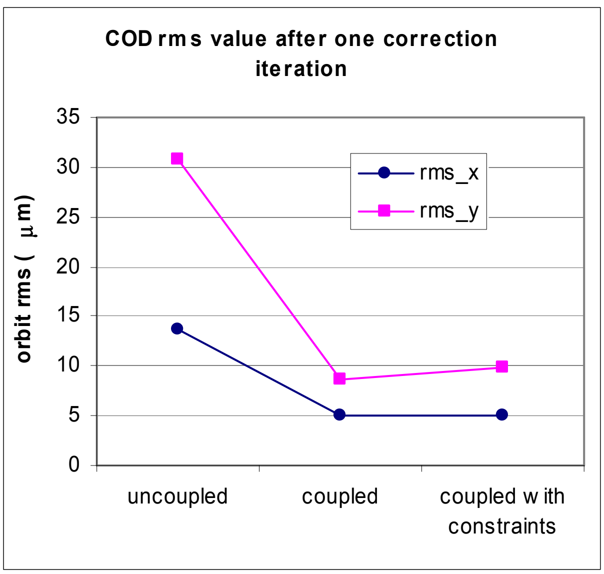

Figure 4: Closed orbit distortion (COD) rms value after one correction iteration with 100% correction. The distorted orbit was generated with the same corrector strength used for response matrix measurement in order to decouple coupling from non-linearity.

NON LINEARITY IN THE OPTICS

To test the response matrix sensitivity to non-linearities introduced by sextupoles in the LNLS ring, we have measured and compared the orbit response matrix for two different sextupole settings. Figure 5 shows the measured difference for sextupoles corresponding to $\xi x = \xi y = +1.0$ and $\xi x = \xi y = -2.0$, where ξx and ξy are, respectively, the horizontal and vertical chromaticities. The results show that the variations caused to the response matrix elements by this effect are about the same order as variations due to the amplitude of the correctors.

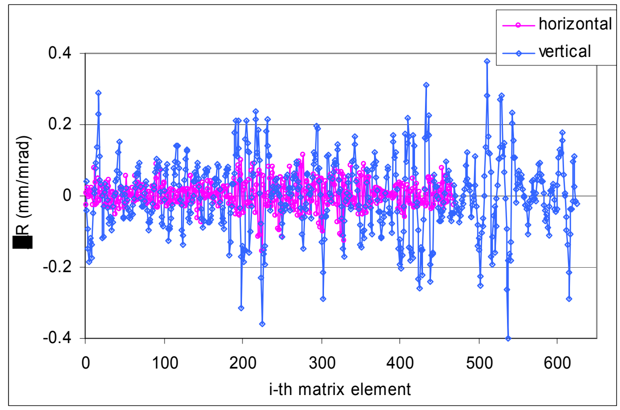

Figure 5: Difference in response matrix measurements for two different sextupole settings. The first setting corresponds to $\xi x = \xi y = +1.0$ and the second setting to $\xi x = \xi y = -2.0$.

CONCLUSIONS

We have tested various hypotheses to explain why we are not able to correct the orbit in just one iteration, even when the measured response matrix is used. The initial guess was coupling, an effect which could be cured by appropriately including the effect in the correction algorithm. In fact, the closed orbit distortion is improved when the measured coupled response matrix is used. This improvement, however, does not eliminate the difficulty we started with. It turns out that the non-linear dependence of the response matrix on the corrector kick amplitude contribute equally to the necessity of a few correction iterations for orbit convergence and we have not yet devised a way of curing this. One possible idea to improve correction prediction, at least for small amplitude distortions, is to measure the response matrix for 'zero' kick by extrapolating successive measurements with a series of kicks. This could be a way of determining the linear part of the response matrix while using reasonably sized kicks that allow good resolution in the orbit measurements.

Although the studied effect is not a serious problem for orbit feedback in the present routine users operation, since small corrections are continuously applied every 24 seconds to basically compensate for slow thermal drifts, an improvement could be obtained for future operation with moving insertion devices, where the correction system is expected to be able to manage situations with faster and bigger orbit changes.

REFERENCES

[1] N. Nakamura et al, 'New orbit correction method uniting global and local orbit corrections', NIM A, 556 (2006) 421-432.