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OPTIMIZATION OF TURN-BY-TURN MEASUREMENTS AT SOLEIL AND ALBA LIGHT SOURCES

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Abstract

Beam position monitor turn-by-turn measurements paves the way for fast storage ring lattice diagnostics. On the other hand turn by turn technique is by its very nature delicate, requiring an extensive system tuning and understanding. During last year several tests to retrieve linear model informations from turn by turn measurements have been carried out in collaboration between the synchrotron of Soleil and Alba. A routine to extract phase advance and betatron amplitude from turn by turn measurements has been developed. Moreover a first attempt to retrieve quadrupole errors from such observables has been done.

INTRODUCTION

To meet the required performance, modern synchrotron light sources demand a fine control over lattice parameters. Lattice assessment methods, usually employed used at Alba and Soleil, are based on slow orbit acquisition (i.e. LOCO [1–3].) The response of the beam orbit to a change of each dipole corrector is recorded and lattice parameters are then fitted to reproduce the experimental results. The robustness of such method resides in the precise but slow orbit change measurements that have to be repeated for a large number of correctors, until a response matrix is obtained. Turn-by-turn measurements represent a fast way to compare the behavior of the machine lattice with respect to the nominal model, resulting in a good candidate to implement rapid optics correction. To validate the capabilities of the turn-by-turn approach a measurement campaign has been launched in conjunction between the synchrotron of Soleil and Alba.

TURN-BY-TURN SETUP

In order to produce good observations of the transverse dynamics, the beam motion has to be excited coherently and kept coherent as long as possible. The excitation is produced by means of a magnetic pinger, with a characteristic pulse time shorter than the revolution period and a pulse profile as flat as possible [4, 5].

On the other hand the delicate coherent motion of electrons is easily washed out by second order effects jointly with the finite emittance of the beam. Especially the dependence of the transverse tunes on the kick amplitude and electrons energy (chromaticity). Such effect can be minimized by properly tuning the sextupoles in the ring [6].

Soleil

The Soleil storage ring is equipped with 122 beam position monitor (BPM) each of them connected to a Libera electron receiver. Even if such receiver system guarantees a high bandwidth, it is till not enought to discern the beam position sampled at successive turns. This phenomenon is commonly known as turn smearing. To cope with this inconvenience a post processing of the data is required, where the response function of the BPM to a single turn signal is deconvoluted from the recorded signal. The response function can be measured by injecting a short train of electron bunches in the ring and dumping it out after exactly one turn.

Alba

The Alba storage ring is equipped with 120 BPMs equipped with the Libera Brilliance receiver [7]. Such receiver can be reprogrammed with a non-standard firmware (MAF [8]), developed originally under request of ESRF, that is immune to the smearing effect. In MAF the turn mixing is avoided by substituting the narrow band infinite impulse response filter, that causes the smearing, with a finite impulse response filter obtained by means of a fixed time integration window. This different filter design requires a special setup procedure, where the integration window is synchronized with the train of bunches traveling in the ring. The synchronization was adjusted by scanning the delay of the window and looking for the maximum of the sum signal from the four BPM's buttons. The MAF design not only avoids the smearing effect but also ensures a lower noise, being the signal integrated only when the train of bunches transits through the BPM. The reduction of the integration time results thus in less noise entering the BPM's demodulation chain.

TURN-BY-TURN ANALYSIS

Turn-by-turn data have been analyzed using the interpolation approach described in [9], that ensures a very precise reconstruction of amplitude and phases information.

Lattice Jitter

In an ideal system without noise the tune signal measured by each BPM is expected to have the same frequency. The observed agreement between different BPM in the same shot is remarkable ($\sigma = 7.0 \times 10^{-7}$). On the other hand a shot to shot fluctuation of the tune frequency is evident($\sigma = 2.3 \times 10^{-4}$) even if small. A similar behavior, but of smaller entities, has been observed also at Soleil. No correlation between the tune fluctuation and the kick strength is observed, nor a simple trend in time of the tune variation. Most likely the source of such fluctuation resides in the residual line-ripple coming from quadrupoles power supplies. Figure 1 shows the tune jitter spectrum. Two main contributions, at 100 Hz and 300 Hz are clearly visible.

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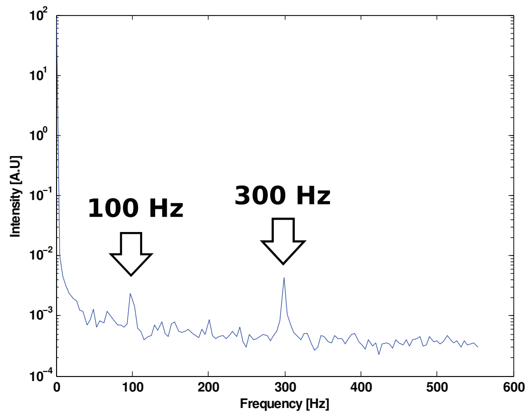

Figure 1: Tune jitter spectrum calculated from an acquisition of 2.5×10^5 turns. Since a kick would not last enough to measure the low frequency components of the spectrum, we relied on the steady excitation from vertical instability to measure over a long period the betatron tune. For this purpose the vertcial chromaticity has been reduced until the vertical instability was visible.

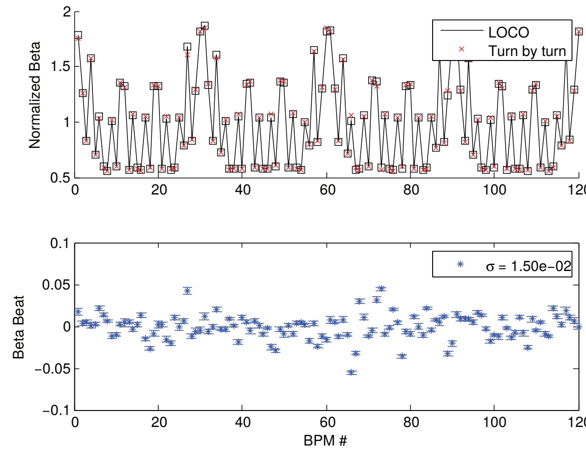

Figure 2: Top: Alba normalized horizontal betatron function from turn-by-turn measurements averaged over 100 kicks compared against the normalized betatron function estimated from LOCO. Bottom: Beta-beat and standard deviation. The error bars represent the reproducibility of the measurements, obtained from the standard deviation of the beta-beat over the 100 acquisitions

Linear Lattice from Turn-by-turn

Two main informations on linear lattice can be easily retrieved from turn-by-turn measurements:

- Betatron amplitude at the BPMs location
- Phase advance between BPMs

Betatron amplitude at the BPM locations can be easily inferred, except for one scale parameter, from the amplitude of the tune lines recorded by each BPM. Two factors contribute to the unknown scaling parameter: the unknown common gain of the BPMs and the strength of the pinger. Even if it is possible to estimate the BPM gains with alternative methods (i.e. LOCO) and measure the strength of the kick by means of magnetic measurements, it is still possible to obtain significant information without an estimation of the scale factor, avoiding the risk of introducing further sources of error. In fact without knowing the scale factor it is possible to define a normalized betatron function ($\bar{\beta}$):

$$\bar{\beta}_i = \frac{A_i^2}{\sum_{j=0}^{N} A_j^2} N,$$

where A_i is the amplitude of the i-th BPM and N is the total number of BPMs. A similar normalized betatron function can be obtained from the lattice model substituting in the previous formula A_i^2 with the beta function estimated from the lattice model. Figure 2 shows the comparison between the model estimated with LOCO and the turn-by-turn measurements. In both cases, Soleil and Alba, a beta-beat about 2% has been observed on both vertical and horizontal planes. No relevant improvement has been observed by correcting each BPM gain with the one estimated by LOCO

Also the tune phase can provide useful information on the linear model. The phase advance between couple of BPMs is calculated and compared against the one expected from LOCO (Fig. 3). A summary of the beta and phase beat obtained at the synchrotron of Soleil and Alba is reported in Table 1, showing a remarkable agreement between turn-by-turn measurements and LOCO. All the beta and phase beat have been obtained by comparing the turn-by-turn measurements with a model estimated with LOCO and after correcting the lattice, by means of LOCO, until a beta-beat smaller than 1% was obtained. The agreement between turn-by-turn measurements and LOCO is remercable The Alba turn-by-turn data have been also analyzed with a different technique developed by a group at CERN with very similar results [10].

QUADRUPOLE ERRORS RECONSTRUCTION

Precise phase-advance and beta measurements make possible to obtain information on the linear lattice errors. At first order, quadrupole errors behave linearly, in other words the total phase-beat and beta-beat can be obtained by adding the contribution of each quadrupole. Thus, by simulating from the storage ring model the beta-beat and phase-beat

Table 1: Beta and phase beat results for Soleil and Alba. The measurements have been acquired after correcting the machine with LOCO to a beta-beat smaller than 1%.

	Soleil	Alba
β-beat (H)	1.9×10^{-2}	1.5×10^{-2}
β-beat (V)	1.8×10^{-2}	1.4×10^{-2}
ϕ-beat (H)	8.5×10^{-3}	5.9×10^{-3}
ϕ-beat (V)	1.3×10^{-2}	4.6×10^{-3}

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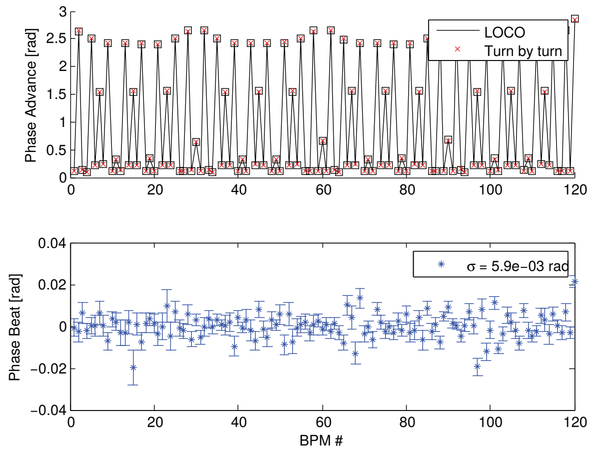

Figure 3: Top: Alba horizontal phase advance turn-by-turn measurements averaged over 100 kicks compared against the estimation from LOCO. Bottom: Phase beat and standard deviation. The error bars represent the reproducibility of the measurements, obtained from the standard deviation of the phase beat over the 100 acquisitions.

produced by a known error on each single quadrupole, it is possible to disentangle each single quadrupole error, provided the measures are accurate enough and enough BPMs are present in the ring.

An experiment to test the ability to observe single quadrupole errors has been carried out on both machines, Soleil and Alba. A set of measurements has been acquired before and after altering, by a known amount, the current powering a quadrupole. The effect of a quadrupole strength error has been estimated from the storage ring model by simulating the response of the lattice functions at the BPM locations for a given change in the strength of each quadrupole. The resulting beta-beat and phase-beat has been collected in a matrix, known as the "beta and phase advance to quadrupole response matrix", such that:

$$M \times \vec{Q} = \vec{\Delta},$$

where M is the response matrix, $\vec{Q}$ is the quadrupole errors vector composed by one component for each quadrupole indicating the error strength while $\vec{\Delta}$ has 4 components for each BPM, representing the beta-beat and phase-beat for the horizontal and vertical planes.

The matrix M is then factorized by running a singular value decomposition. A cut was operated discarding all the components having a corresponding singular value lower than a threshold (threshold = 0.017) fixed by trial and error. The remaining components are used to build an inverse matrix of M, such that:

$$\vec{Q} = M^{-1} \times \vec{\Delta}.$$

Thus by substituting the $\vec{\Delta}$ vector with the results for beta-beat and phase-beat obtained from turn-by-turn measurements, it is possible to get a guess of the location and strength of the quadrupoles error.

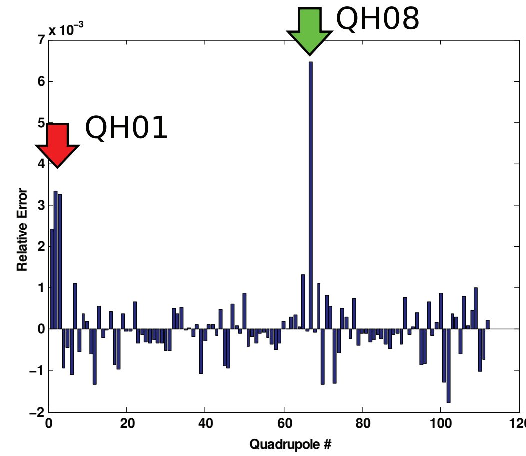

Figure 4: Quadrupoles errors reconstructed from turn-by-turn measurements in the Alba storage ring. The two arrows indicate the locations where the strength of two quadruoles has been modified by 1%.

Figure 4 shows the difference of the reconstructed quadrupolar errors between the two dataset, acquired before and after having applied a known error in the lattice. An error of 1% was introduced in two quadrupole: QH01 and QH08. The presence of the error in QH08 is clearly identified even if the error strength is underestimated by 30%. The magnet QH01 was selected on purpose, being very close to other two magnets. In this case the reconstruction fails to identify precisely the source of error and the fault appears to be shared within the three neighbours magnets. The overall noise floor is rather contained (~ 0.05% RMS).

CONCLUSION

For the first time turn-by-turn measurements has been employed at the Alba and Soleil Synchrotron as a fast linear model assessment tool with very promising results. The measured linear lattice parameters, beta and phase beat, match very well the prediction obtained with LOCO. A first test to verify the ability to retrieve linear lattice errors has been performed with encouraging results. Nevertheless, a complete optic correction based on turn-by-turn measurements is still to be proved. In fact even if the quality of the measured turn-by-turn data is remarkable, the amount of collected information is limited to 4 observables for each BPM (horizontal and vertical beta and phase beat), as opposed to the closed orbit correction methods where, the manipulation of each corrector provides two different observables for each BPM (horizontal and vertical orbit). In other words the large number of correctors present in the ring is exploited to increase the number of observables and positions where the lattice is sampled resulting in a much more complete picture of the optics.

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