FIRST TURN-BY-TURN MEASUREMENTS FOR BEAM DYNAMICS STUDIES AT ALBA

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Abstract

This paper summarizes the tasks carried out to develop a turn-by-turn (TBT) measurement system at ALBA. These tasks mainly include testing the MAF firmware for the Libera BPMs and implementing the necessary analytical tools to infer the beam dynamics parameters. TBT measurements using an injection kicker are presented. Linear and non-linear beam dynamics results are compared with LOCO. The results are still preliminary since a good agreement with the linear model has not been achieved yet.

INTRODUCTION

LOCO [1] is the default and most used tool to evaluate the machine linear optics at ALBA. To crosscheck its results, TBT data analysis is a good candidate. In next section the theoretical bases for such measurements are exposed. In the third section the setup at ALBA is described. Finally some preliminary results are shown.

Beta from Amplitude

The transverse linear motion $x_{b,n}$ at every turn n of an electron beam at every BPM b can be parametrized as:

$$x_{b,n} = \sqrt{2J_n\beta_b}cos(2\pi n\nu + \phi_b) \tag{1}$$

where J_n is the action at every turn, β_b is the usual Twiss parameter, ν is the tune and ϕ_b is the betatron phase at each BPM. At ALBA, up to 24 couples of BPMs do not have any linear element in between. For each couple c, the linear angle $x'_{c,n}$ can be parametrized as:

$$\begin{aligned} x'_{c,n} = \frac{x_{c+1,n} - x_{c,n}}{L_{c+1,c}} &= -\alpha_c\sqrt{2J_n/\beta_c}cos(2\pi n\nu + \phi_c) \\ &- \sqrt{2J_n/\beta_c}sin(2\pi n\nu + \phi_c) \end{aligned} \tag{2}$$

Where now $L_{c+1,c}$ is the distance between BPM c and $c+1$ and α_c is the usual Twiss parameter. Every few turns, knowing $x_{c,n}$ and $x'_{c,n}$, the one turn transport matrix can be fitted. This allows to calculate α_c, β_c and γ_c and finally also J_n. The average among the BPM couples allows a good fit of the action J_n which can be used to normalize the position at every BPM. By fast Fourier transform (FFT) analysis of the normalized linear position, β_b and ϕ_b can be inferred at every BPM.

BPM Calibration

Mechanical and electrical imperfections produce different systematic proportional error at every BPM. This so called calibration error, produces in turn a systematic error measurement of the above mentioned parameters. This error affects the determination of both the action and the beta but not the betatron phase. LOCO [1] is supposed to be able to fit such calibration errors. However, up to now, taking into account the reconstructed errors in the TBT measurements does not make the result closer to LOCO's.

Beta from Phase

The above mentioned calibration problem is a reason why an alternative method to calculate the beta beat from the phase beat is used [2]. Given 3 close by BPMs, lets call them 1, 2, and 3, the beta beat can be extrapolated using Eq. 3:

$$\beta_2 = \beta_2^0\frac{sin(\Delta\phi_{13})sin(\Delta\phi_{12}^0)sin(\Delta\phi_{23}^0)}{sin(\Delta\phi_{13}^0)sin(\Delta\phi_{12})sin(\Delta\phi_{23})} \tag{3}$$

where the superindex 0 indicates a value given by the unperturbed model. This relation holds only if there is no lattice errors between these BPMs and the phase advance between them accomplishes the condition:

$$\begin{aligned} \Delta\phi &= \frac{\pi}{4} + m\frac{\pi}{2} \qquad \forall m \in \mathbb{N} \\ \Delta\phi &\neq m\pi \qquad\qquad \forall m \in \mathbb{N} \end{aligned} \tag{4}$$

According to Ref. [3], for every BPM several sets with 2 additional BPMs can be established. The average of Eq. 3 over the BPM sets leads to a more precise result. For each set, Eq. 4 must be satisfied. Also, only close by BPMs can be used, since Eq. 3 holds only when there are no large lattice error between the BPMs. Simulations show that the level of agreement should be below ± 3%.

Sextupolar Observable Resonant Driving Term

Equation 1 can be slightly more realistic including the first order driving term, named $F_{NS3,b}$, generated by the normal sextupoles in the machine [4]:

$$\begin{aligned} \frac{x_{b,n}}{\sqrt{\beta_b}} &= \sqrt{2J_n}cos(2\pi n\nu + \phi_b) \\ &- 4J_n|F_{NS3,b}|sin(4\pi n\nu + 2\phi_b - \angle F_{NS3,b}) \end{aligned} \tag{5}$$

In the reference [4], the expression of $F_{NS3,b}$ as a function of the sextupole fields in the machine and the linear optics functions is given. Similarly to the linear case, $F_{NS3,b}$ can be measured for every BPM by FFT analysis (both real and imaginary parts). If the BPM calibration is unknown, Eq. 5 can be normalized with the tune peak height. In this case, the measured quantity would be $2\sqrt{2J_n}F_{NS3,b}$. As in the

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linear case, J_n can be evaluated at every BPM couple. Still the average of J_n over the BPM couples may depend on the mean BPM calibration. This kind of measurements may lead to the sextupolar fields fit. As suggested in [4], a dedicated sextupole setting that avoids decoherence (low chromaticity) has been used with these measurements.

TBT MEASUREMENT SETUP

BPM Electronics and Firmware

A Libera Brilliance electronics module is connected to each one of the 120 BPMs of the ALBA storage ring [5]. The standard firmware suffers from signal mixing between neighboring turns. This can be avoided with its anti/smearing filter, but that requires precise synchronization. Also, its integration window can not be varied. This results in a difficult synchronization procedure. An alternative firmware, developed at ESRF, containing a moving average filter (MAF) has also been tested [6].

Kicker Magnet

In absence of a dedicated pinger magnet, one of the 4 injection kickers is used to excite the beam oscillations. The maximum kicker strength is 9.7 mrad, but for our studies the settings range from 0.1 to 0.5 mrad. This makes the kicker quite inaccurate in our range of study. The kicker pulse has a half sinus shape and lasts 5 turns. However, at low voltages, relevant tails before and after the pulse appear affecting up to 20 turns after and before it. For this reason, the first 20 turns are discarded. Moreover, the injection kicker limits the study to the horizontal plane, so all data showed in this study refers to the horizontal plane.

Filling Pattern

Given the peculiarities of the injection kicker pulse, different amplitudes and phases are seen at different parts of the beam. According to simulations, the action along the ring is expected to vary around 10% and the phase 1 rad. For this reason, a filling pattern consisting in a single train of 32 buckets out of 448 is used for the TBT measurements. In the worst case, the accumulated kick variation around the train would be ± 1% in amplitude and 0.01 rad in phase. With the MAF firmware, the BPM integrating window is set to accommodate the whole train. Hence, in that case the synchronization effects should be small. However, with the standard firmware, since the integration window is one turn, synchronization directly affects the amplitude and the phase measurements.

BPM SYNCHRONIZATION

The BPM synchronization has been done independently for the two available firmwares. MAF firmware allows to change its integration window. This makes possible synchronizing with stored beam which gives better signal and results. In the standard case this is not true, the integration window is a full turn and only single pas beams can be used for the synchronization. The two procedures are the following:

1. Standard firmware: A single train killed after the first turn is send to the SR (0.5 mA approx.). The TimePhase attribute of the BPMs is scanned in units. For each BPM the right TimePhase is found when the previous and following turns have an equal Sum signal.
2. MAF firmware: In this case up to 15 mA are stored. A narrow integrating window of 32 bucket (64 ns) is used. For each BPM the right MAF delay is found when the average Sum signal is maximum.

In both cases, the scan granularity is given by the timing system: 4 buckets (8ns). ALBA's nominal horizontal tune is 18.155 and the revolution time is 897 ns. This does not affect the phase measurement with the MAF filter. However, with the one turn integration window of the standard filter, this time granularity corresponds to a phase granularity around 0.01 rad. The TBT phase with both filters has been compared to the corresponding LOCO fit [7]. 30 measurements of 1024 turns for all 120 BPMs have been acquired. The results are shown in Fig. 1. MAF results indicate the level of phase error of the LOCO fit. Including the phase error in the linear model fit as in [4] is being studied. Unfortunately, for some BPMs, the MAF firmware behaved very strangely (from BPM 80 to 100 in Fig. 1). The origin of such strange behavior has not been clarified yet. The results with the standard firmware show some mis-synchronization. This prevents from applying anti-smearing filters that are installed with the standard firmware.

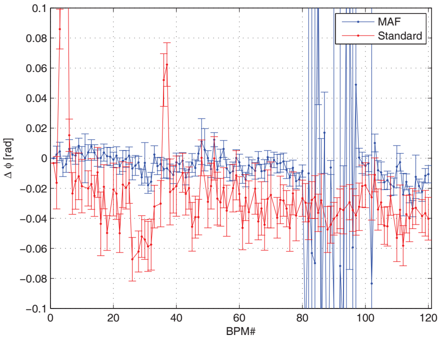

Figure 1: Phase error with respect to the LOCO fitted model. Both Firmware results are shown.

PRELIMINARY RESULTS

Beta from Amplitude

The beta values are compared to the LOCO fitted model in Fig. 2. With the standard firmware the agreement with the model is within ±10%. With the MAF firmware the agreement with the model is within ±4%. Assuming the LOCO BPM fitted gains, the beta values for the TBT data have been recalculated. However, in general this does not make the beta beat with respect to LOCO decrease. This again indicates a disagreement at the level of the linear model.

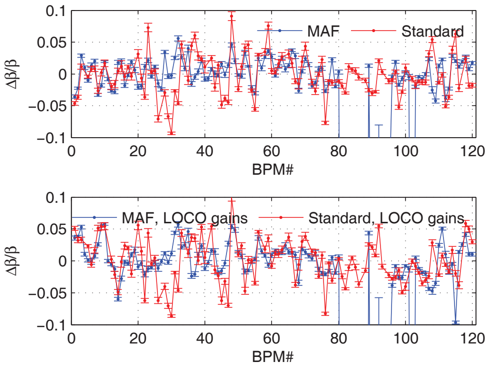

Figure 2: Beta beat from TBT amplitude measurements for every BPM. Both Firmware results are shown. The effect of the LOCO BPM calibration is shown.

Beta from Phase

Results are shown in Fig. 3 .Using both firmwares, the beta calculated from the phase is less precise and further away from the model than the beta from the amplitude. The values are to close to the expected disagreement (this method assumes small linear errors) using this method (± 3%) to draw any conclusion.

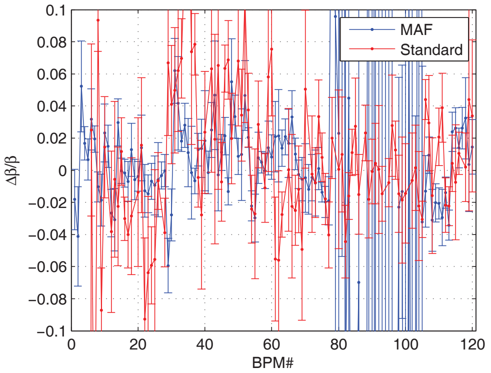

Figure 3: Beta beat from TBT phase measurements for every BPM. Both Firmware results are shown.

Observable Driving Terms

Results are shown in Fig. 4. The differences with respect to the model are quite large, above ±50%. This results are compatible with ±3% RMS sextupolar errors in the machine but also with ±10% uncontrolled beta beatings in the linear model.

CONCLUSION

At ALBA, TBT data provides linear optics with a level of agreement with LOCO from ±4% to ±10% depending on the method and firmware. The TBT phase difference with respect to LOCO suggests that LOCO contains some uncontrolled errors in the fit. We consider that calibration of the BPMs is not known yet. The agreement with the non linear parameter $F_{NS3,b}$ is above ±50%. The origin of this discrepancy can not be resolved until our linear model has a better agreement.

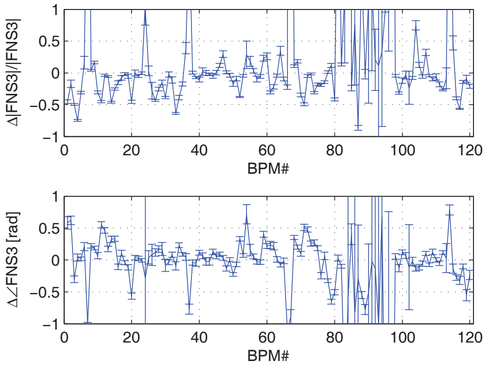

Figure 4: Observable RTDs error from TBT data for every BPM. Only MAF firmware was used. Both amplitude (upper plot) and phase (lower plot) are shown.

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