ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEOZSP4

FULL COUPLING STUDIES AT ALBA

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Abstract

As other low emittance machine upgrades ALBA-II proposal considers operating in full coupling. In such configuration the horizontal emittance is further reduced while the lifetime is increased at the price of working close to equal fractional tunes. This mode of operation has not been adopted by any existing light source to date, and it presents a few disadvantages, like the optics degradation, injection efficiency reduction and beam size stability. In this paper the above mentioned difficulties are studied for the present ALBA storage ring in full coupling conditions.

INTRODUCTION

To ensure a proper beam lifetime, several future low emittance light sources designs [1–4] rely on the ability to operate on or next to the coupling resonance $Q_x = Q_y + n$, where $Q_{x,y}$ are the horizontal and vertical tunes and n is an integer. Such constraint on the working point is not used on the operation of existing light sources, which has triggered several studies in such working conditions [5–7]. The injection schemes, the physical apertures aspect ratio and the non-linear strength of future low emittance light sources differ substantially from present machines. The experience in present light sources in full coupling can not be extrapolated directly, however achieving a good agreement with simulations is a first step towards relaying on this type of operation.

Working in full coupling changes the constraints given by the collective effects. Up to now, for the ALBA case we have found that such changes are mostly beneficial.

Other groups [8, 9] have studied the possibility to generate the same full coupling effects in terms of lifetime gain and horizontal emittance reduction without the considerable optics design constraint of the coupling resonance condition. In that case an AC skew quadrupolar field excited at a $Q_x - Q_y$ frequency is used. Some first tests have been performed in the present ALBA machine in order to check our understanding of such technique and in the future this possibility will be further explored for the ALBA-II design.

None of the above is used in present light-sources, instead, in the case of the EBS, a vertical dipolar white noise excitation has been successfully used in operation [10].

LATTICE CONFIGURATIONS

Full coupling operation of future low emittance lattices requires an optimization of the coupling strength $|C_0|$ [11]. On one side, a larger C_0 implies a wider coupling resonance, and so a more stable machine operation (against power supply noise, insertion device errors, etc). On the other hand, near the resonance a high coupling strength produces an optics distortion which potentially translates to worse dynamical aperture and injection efficiency.

Our simulations for ALBA-II indicate that the optics correction near the coupling resonance requires also tuning the skew quadrupole correctors. Therefore, the distribution of the skew quadrupole strengths should be a key issue. In this first work we have not studied that in detail.

When setting up the full coupling lattice, the optics was first corrected with LOCO [12] without applying any skew quadupole change. Based on that same normal quadrupole settings, the measurements described in the next sections have been carried out for three different skew quadupole configurations:

- corrected: LOCO based skew quadrupoles (applied after two iterations);
- not corrected: no skew quadrupoles applied with;
- anti corrected: LOCO based skew quadrupoles applied with opposite polarity.

Each of the configurations was later analyzed with a LOCO measurement. Here the coupling strength has been calculated using the analytical formula described in [11]. The optics degradation in terms of beta beating is between 2.5% and 5.7% which we think should have no major effects on the measurements.

COUPLING MEASUREMENT

The global coupling in a ring is typically defined as the emittance ratio $k = \epsilon_y/\epsilon_x$ which in this case is measured in two different methods:

- from the emittance ratio at the pinhole locations;
- from the turn by turn (TbT) action transfer ratio at the beam position monitors (BPM).

The first method consists in calculating the emittance from the measured beam sizes $\sigma_{x,y}$ at the pinhole cameras, the modelled optical functions (obtained via a LOCO measurement) $\beta_{x,y}$ and $\eta_{x,y}$ and the modelled energy spread σ_δ:

$$\epsilon_{x,y} = \frac{\sigma_{x,y}^2 - (\sigma_\delta \eta_{x,y})^2}{\beta_{x,y}}. \quad (1)$$

The second method is described in [13]. In this case the TbT BPM readings after a pinger kick are analyzed via Fourier decomposition. The two main spectral lines (the horizontal and vertical tunes, as here we assume no other relevant lines) amplitudes a_1 and a_2 determine the action transfer. The amplitude squared a^2 (proportional to the action) along the turns n can be expressed as:

$$a^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\left((Q_1 - Q_2)2\pi n + \mu_1 - \mu_2\right), \quad (2)$$

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where $Q_{1,2}$, and $\mu_{1,2}$ are the corresponding tunes and phase obtained in the Fourier analysis. The coupling is defined as the ratio of the sums of the transferred actions and the motion action:

$$k_{TbT} = \frac{2a_1a_2}{a_1^2 + a_2^2}. \quad (3)$$

This calculation is visualized in Fig. 1 showing a real TbT acquisition and the action transfer ratio calculation. In that case the signal decay constant was also fitted in the analysis to account for the radiation damping.

Decoherence in the TbT measurements is difficult to distinguish from action transfer. To avoid it we acquire the data after having reduced the chromaticity to 0.5 in both planes while ensuring that the beam is stable. Also a filling pattern with just one tenth of the buckets of the ring is used which limited the stored current to 20 mA in all the measurements.

According to our simulations using AT [14] for the ALBA lattice the coupling k using Eq. (1) and k_{TbT} using Eq. (3) are equivalent.

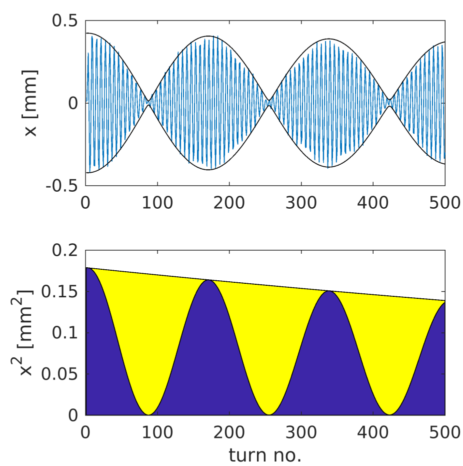

Figure 1: TbT measurement showing almost 100 % action transfer. The upper plot shows the TbT readings (light blue line) and the amplitude (black line) obtained from the two higher spectral lines. The lower plot shows the squared amplitude (blue area, proportional to the denominator in Eq. 3) and the transferred squared amplitude (yellow area, proportional to the numerator in Eq. 3).

For both measurement techniques, the coupling strength is fitted assuming the following relation close to the resonance:

$$k = \alpha_1 + \frac{\alpha_2}{1 + \frac{\Delta^2}{(C_0+\alpha_3\Delta)^2}}, \quad (4)$$

where α_1, α_2 and α_3 are fitting parameters representing respectively the residual (operation) coupling (in the order of 0.005), the coupling max amplitude, and the assymetry around the tune resonance. $\Delta = Q_x - Q_y$ is the tune difference.

TUNE SCAN THROUGH THE RESONANCE

The ALBA usual working point is $(0.152, 0.362)$, but to operate near full coupling we used a new optics at $(0.161, 0.161)$. We use a specific "step tune" function to minimize the optics beating along the tune scan and keep it in all cases < 5% .

To calculate the beam emittance, we rely on 2 x-ray pinhole cameras taking light from 2 different dipoles [15, 16]. We take the emittance as the average between the two values, while the error bar is taken from their difference (the repeatability of the individual measurement is bigger than the discrepancy between them). The pinhole calibration error was measured to be < 2% using a beam based technique, consisting on fitting the response of the beam centroid at the pinhole to all the orbit corrector magnets.

For the TbT coupling measurement, the average over 120 BPMs for 10 acquisitions of up to 2000 turns is use. That is equivalent to roughly 2 ms which makes this measurement more suitable to detect fast variations of the coupling. In this case the repeatability of the individual BPM measurement and the discrepancy between BPMs are at the same level. The tune measurement is done using the same 120 BPM TbT data but only for the first 32 turns using the technique described in [17], so that the measured tune is weakly affected by the coupling (as the action transfer effect is largely avoided). Nevertheless, it is worth mentioning that due to the noise in the magnets power supplies, the tunes at each working point have an rms fluctuation of $(2.6, 1.2) \cdot 10^{-4}$ in the (hor, ver) planes.

The results of the coupling measurements with the pinhole and TbT techniques are shown in Fig. 2. The fitted coupling stregth is displayed in the legend. The adjusted LOCO model's tune is scanned to simulate the coupling along the scans (dashed lines).

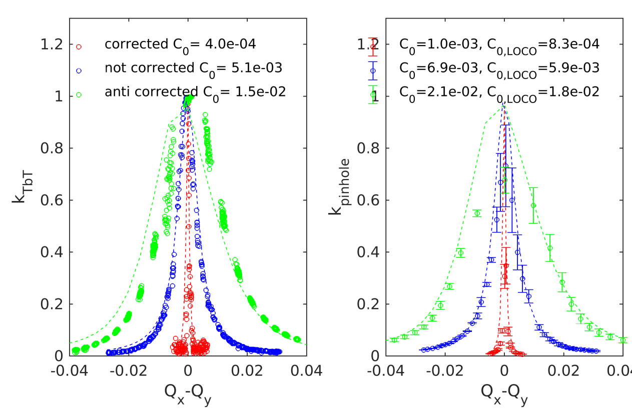

Figure 2: Coupling measurements and simulation through the resonance. TbT coupling is shown in the left hand side plot, the pinhole based measurements are shown on the right hand side plot and the LOCO simulations are shown in both plots with dashed lines.

Unlike the TbT measurements and the LOCO simulations, the pinhole based measurements do not reach the 100% cou-

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pling in any case. Both the beam size measurement and the LOCO fit may carry significant systematic errors while the TbT measurement does not relay on any calibration. For these reasons we tend to rely more on the measured TbT coupling. The measured TbT coupling strength is around 20% below the simulated value from the LOCO model except in the corrected coupling case.

DYNAMIC APERTURE AND INJECTION EFFICIENCY

In order to measure the horizontal Dynamic Aperture (DA), we use a single injection kicker sequentially increasing its voltage until the beam is lost. At each voltage step the TbT position at the BPM before and after the injection section is recorded up to 15 times, during this time the beam loss monitor (BLM) integrated counts are also acquired (10 seconds integration). We define the horizontal DA as the average of the maximum TbT position of the two BPMs for the voltage step that has the maximum total BLM counts. The same lattices and beam parameters of the previous section are used. The Injection Efficiency (IE) was averaged during the injection process from 0 mA to 20 mA . The measurements were acquired with two different configurations of the vertical scraper, at the usual operation position (±4.75 mm) and at an open position (±10.0 mm).

In all simulations the septum magnet is assumed to be at its design position of -16 mm.

Table 1 shows the obtained results. The DA agreement with respect to the LOCO simulations is quite remarkable in all cases except with the not corrected skews and closed vertical scraper. For this particular case the DA measurement seems as good as in all the other cases with the scraper open, however the IE is quite lower. So far, this discrepancy is not well understood.

Table 1: Measured DA and IE for the three skew quadrupole settings and both vertical scraper positions. The values in brackets correspond to the simulated DA values.

	DA [mm]		IE [%]	
V. scraper	Closed	Open	Closed	Open
corrected	14.6 (15.4)	14.8 (15.4)	84	91
not corrected	14.6 (10.0)	14.6 (15.1)	70	91
anti corrected	6.3 (6.3)	14.8 (15.0)	5	87

STABILITY THRESHOLDS

Both the single bunch and multi bunch threshold have been measured for the three lattices considered. As in the case of the standard machine, the single bunch current threshold is 8.5 mA at zero chromaticity. In the multi bunch case, the current threshold in full coupling was 65 mA while with the standard lattice it was 40 mA.

SKEW AC EXCITATION

In order to excite with an AC skew quadrupolar field, the 4-electrode tune excitation strip-line cables are swapped. Since the tunes do not need to coincide, the standard ALBA lattice with tunes $(0.162, 0.372)$ is used. In this case the TbT coupling measurement as previously described is not possible. First because the skew quadrupole strength given by the strip-line is small ($7.8 \cdot 10^{-5}$ m^{-1}) and it takes 10000 turns to share the emittance, which is much longer than the damping times, so the TbT signals do not resemble those of Fig. 1 at all. Also because in the case of the AC induced coupling the TbT data of one plane does not contain the tune line of the other. Since TbT data is not acquired, the standard operation conditions are used regarding both to the beam filling pattern (440 out of 448 buckets) and the chromaticity (3 units in each plane).

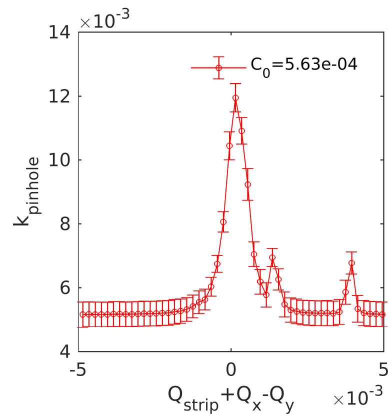

Figure 3: Coupling pinhole measurements scanning the strip-line frequency.

Figure 3 shows the average of the two pinholes for up to 6 different measurements while scanning the tune resonance using the stripline frequency. We are still trying to improve or simulations to include both the radiation damping and the power supply noise. So far we obtain a peak coupling of 0.066 (measured 0.012) and a coupling strength $4.1 \cdot 10^{-4}$ (measured $5.6 \cdot 10^{-4}$).

CONCLUSION AND OUTLOOK

We have determined that LOCO based simulations are able to describe reasonably well highly coupled lattices. That gives confidence in the possibility to design and foresee the operation of future light sources working in full coupling. We expect that this good agreement with simulations will allow to specify a tune stability tolerance for ALBA-II given the injection constrains on dynamical aperture and the users requirements for beam size stability. In future works we should explore the possibility to produce the same coupling strengths distributed differently along the ring so that the optics effects are minimized.

ACKNOWLEDGEMENTS

The authors wish to thank Andrea Franchi (ESRF) for many helpful discussions. The authors also want to thank Andriy Nosych for his help setting up the pinhole and the image analysis.

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