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ANALYSIS OF MULTI-BUNCH INSTABILITIES AT ALBA USING A TRANSVERSE FEEDBACK SYSTEM

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Abstract

Since 2015 Alba is equipped with a transverse bunch by bunch feedback system, which not only damps the transverse coupled bunch instabilities in the machine, but also allows the impedance characterization of the storage ring. This characterization is produced by an internal sequence, which is programmed to excite and measure the growth and damping rates of each of the multi-bunch modes. This paper describes the measurement technique, presents the studies carried out to characterize the machine and different movable systems like the scrapers or in-vacuum undulators. Results are compared with the transverse impedance spectra obtained from computer simulations.

INTRODUCTION

Transverse betatron oscillations associated with beam instabilities limit the machine performance in current synchrotron light sources. These instabilities are driven by long range wakefields, usually trapped modes in cavity-like structures in the vacuum chamber, resistive wall (RW) impedances, and occasionally from multibunch ion instabilities when the machine vacuum is not the optimum.

Since 2015, ALBA uses the transverse bunch-by-bunch (BBB) feedback system described in [1] to damp these instabilities. It is based on the Libera BBB electronics (iTech) and controlled using the firmware and software developed at Diamond Light Source (DLS) [2,3]. This system not only allows to damp instabilities, but it also allows to program sequences that apply different control parameters at the same time as data acquisition. This is used to measure the growth rates of the individual multi-bunch modes, and so to 1) evaluate the ALBA impedance model, and 2) assess the most dangerous modes for the ALBA Storage Ring.

In this report, similarly to what is done in [4], we analyze the results of these scans for different machine configurations, like different chroms or different position of movable systems like scrapers or in-vacuum undulators (IVUs).

IMPEDANCE THEORY

For a beam with M bunches and N particles per bunch and non-zero chromaticity ξ, the complex frequency shift of mode (m,l) is [4,5]:

$$\Omega_{m,l}-\omega_\beta = -i\frac{MNr_0c}{2\gamma T_0^2\omega_\beta}\sum Z_\perp(\omega_{m,l}\cdot h_l(\omega_{m,l}-\omega_\xi)) \ , \quad (1)$$

where r_0 the classical radius of the electron, c is the speed of light, γ is the Lorentz factor, and T_0 is the revolution period. While the $\mathrm{Re}(\Omega_{m,l})$ corresponds to the coherent beam frequency shift, the $\mathrm{Im}(\Omega_{m,l})$ corresponds to the growth rate of mode (m,l), which we will measure experimentally using the BBB in the following sections.

The oscillation frequency of the discrete modes (m,l) is:

$$\omega_{m,l} = (pM+m)\omega_0 + \omega_\beta + l\omega_s \ , \quad (2)$$

with $p = [-\infty, +\infty]$, and ω_0, ω_β, ω_s the (angular) revolution, betatron and synchrotron frequencies. We note that the spectrum of a real signal is folded anti-symmetrically around half of the harmonic number, $h/2$, so that the peak at m_0 has its mirror at $(h-m_0)$ [4,5].

But to infer the beam growth rate of mode (m,l), it is crucial to have a good impedance model $Z_\perp$ in Eq. 1. At ALBA, the contribution of $Z_\perp$ is considered to be composed of two parts, namely the Resistive Wall (RW) $Z_\perp^{RW}$ contribution and the narrow-band resonators $\sum Z_\perp^{\mathrm{res}}$:

$$Z_\perp = Z_\perp^{RW} + \sum Z_\perp^{\mathrm{res}} \ . \quad (3)$$

These two contributions can be expressed as:

$$Z_\perp^{RW} = G_1 L\frac{\mathrm{sgn}(\omega)+i}{\pi b^3}\sqrt{\frac{Z_0\rho c}{2\omega}}, \quad \text{and} \quad (4)$$

$$Z_\perp^{\mathrm{res}} = \frac{R_S}{\frac{\omega}{\omega_r}+iQ\left(\left(\frac{\omega}{\omega_r}\right)^2-1\right)} \ . \quad (5)$$

Here, b is the chamber half-aperture, G_1 is the chamber form Yukoya factor, Z_0 is the vacuum impedance and ρ is the chamber resistivity, R_s is the resonator shunt impedance, Q its quality factor, and ω_r is the resonator eigenfrequency.

Next, we compare the BBB measurements with the impedance model assuming the contributions described by Eq. 3. For simplicity, we assume $l = 1$ and so we will refer to the excitation modes simply as mode m.

EXPERIMENTAL SETUP

We program the BBB to produce a "super-sequence" with the following steps:

- excite mode "m" during 250 turns at the frequency given by Eq. 2;
- leave the BBB inactive to characterize the evolution of mode "m" during the following 500 turns;
- switch the feedback "on" to damp the (possible) instability created by mode "m" for the next 500 turns.

The sequence is then repeated for mode "m+1" and a full characterization spans up to mode 448 (ALBA harmonic

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number), and it takes only few seconds. The number of turns at each step is optimized in a try-and-error method to obtain the growth rate fits more precisely.

Figure 1 shows the evolution of mode "m=255" for ξ=0 following the sequence described before: the beam is excited at mode "m=255" during the first 250 turns (blue points). Next, the excitation is stopped and we observe its growth rate (red points): in this case, since the evolution shows a positive slope, it indicates that this particular mode is unstable (on the contrary, a negative slope would indicate damping). The mode growth rate is obtained from the linear fit to the red points. Finally, we force the beam damping by activating the BBB feedback to stabilize the beam (green dots).

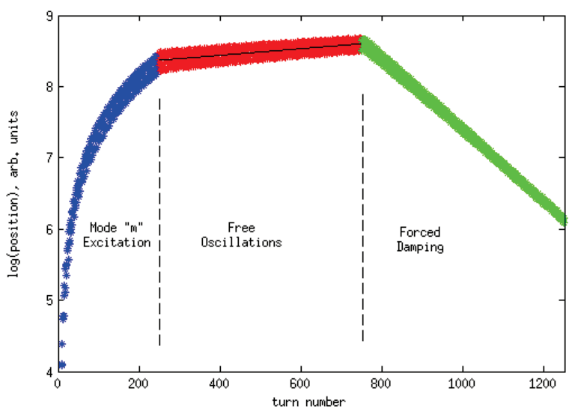

Figure 1: Amplitude evolution (log scale) during the acquisition sequence for mode m=255.

MODEL COMPARISON

In the following, we focus our analysis in the vertical plane, since this is the most critical plane in practice.

In order to evaluate the ALBA impedance model, ZAP simulations following the Zotter formalism [6] are performed. We assume a RW-based model, with Insertion Devices (IDs) closed, vertical chrom. $\xi = 0$, and a full-filling pattern (all possible bunches are filled, i.e. 448). Figure 2 (red curve) shows this simulation, with an additional resonator at $m = 255$ later identified with the vertical scraper) that has been added to match the BBB observations.

Using the BBB, a beam of 100 mA is stabilized in these conditions, and then we performed the mode scan shown in Fig. 2 (blue trace), where the contribution of the radiation damping has been removed to be compared with the ZAP simulations. While the central part is fitted reasonably well, the edges of the spectrum are not well fitted by the model. These differences are not well u nderstood. They point towards the RW-model used in this simulation, which might not be good enough due to: 1) improve the RW model, and 2) add BBR corresponding to the the geometrical impedance, as in Ref. [7] it is seen that this part contributes significantly to the impedance budget. We do not rule out even the possible noise in the BBB acquisition system.

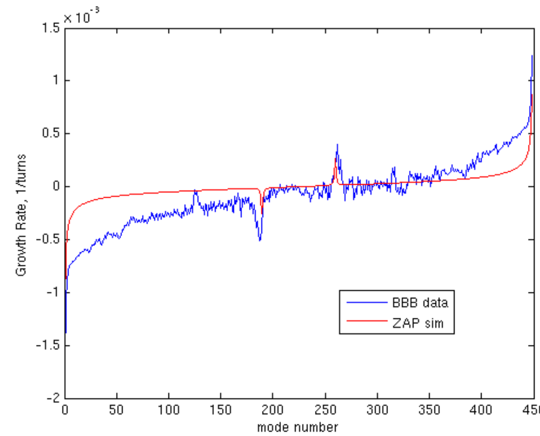

Figure 2: BBB mode spectra for different 100 mA (blue), and fit using ZAP simulations (red).

EFFECT OF VERTICAL CHROMATICITY

Figure 3 shows the growth rate for all possible modes when the vertical chromaticity is varied, all the Insertion Devices (IDs) are open, and the machine is filled with 250 mA in a 90% filling pattern.

Note that the curves in Fig. 3 for the different vertical chromaticities are almost parallel, and they are shifted down as we increase the chromaticity indicating a more stable beam due to headtail damping. In fact, by subtracting the difference in the growth rates for each mode in Fig. 3, we can evaluate the additional damping rate produced by a ξ step. If we call the growth rate at mode m as $\alpha^{\xi}{}_m$ the average growth rate per step of ξ can be inferred by:

$$\langle \frac{\Delta\alpha}{\Delta\xi} \rangle = \frac{1}{h} \sum_{m=1}^{h=448} \sum_{i} \frac{\alpha_m^{\xi_{i+1}} - \alpha_m^{\xi_i}}{\xi_{i+1} - \xi_i}, \qquad (6)$$

where i runs on the different ξ in Fig. 3. The distribution of the different components on the rhs of Eq. (6) is shown in Fig. 4: each chromaticity step produces an additional damping rate of $\langle \frac{\Delta\alpha}{\Delta\xi} \rangle = (1.5 \pm 0.3) \cdot 10^{-4}$ 1/turns.

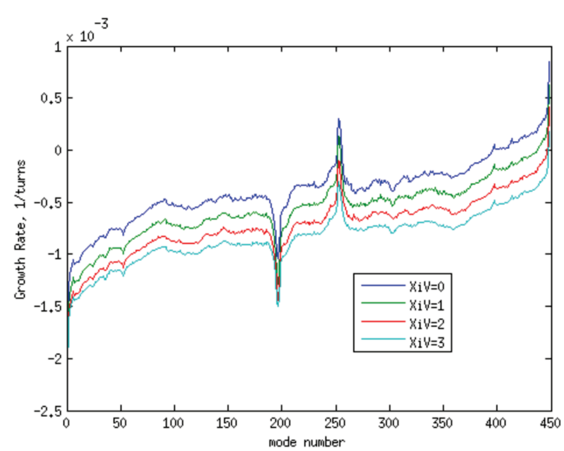

Figure 3: Mode spectra for different ver chroms and 250mA.

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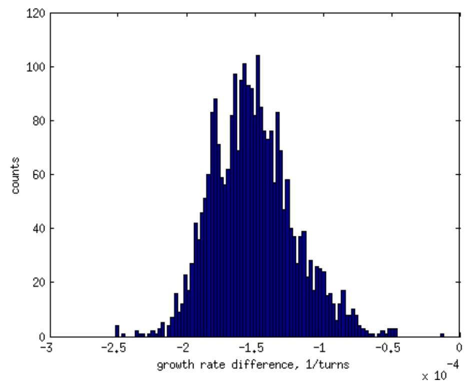

Figure 4: Histogram of $\langle\frac{\Delta\alpha}{\Delta\xi}\rangle$, growth rate difference per chromaticity step for all possible modes (see Eq. (6)).

VERTICAL SCRAPER

Figure 5 shows the scan for the different vertical scraper gaps. One can see that, as we close the scraper to narrower gaps, the peaks in Fig. 2 drift from $m_0 = 255$ for the scraper nominal gap (9.5 mm) towards larger mode numbers. Furthermore, the peak amplitude increases as we close the gap, going above zero (instability threshold) for gap ~8.0 mm. Note the clear anti-symmetry of the peaks around h/2=224, as it is characteristic of the impedance mode spectrum.

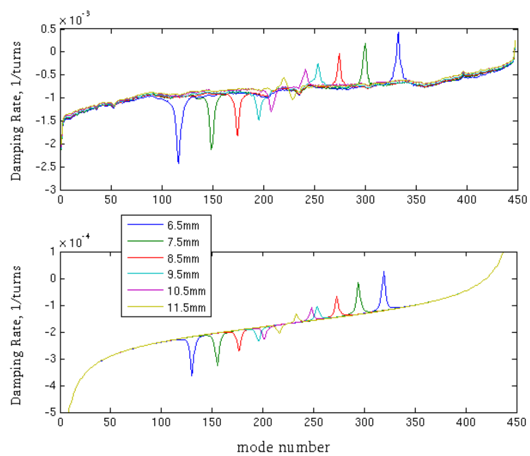

Figure 5: BBB mode spectra for different scraper gaps.

The behaviour of the scraper is reproduced with GdfidL simulations [8] using a simplified geometry of the vacuum chamber and the scraper jaws. The simulations reproduce very well the drift in the peak position vs the scraper gap (see Fig. 5). There is a difference of about 14 modes, which corresponds to a frequency of 15 MHz (recall f_{rev}=1.12 MHz at ALBA). On the other hand, the growth rate shows only a good qualitative agreement for the peak amplitude which corresponds to about a factor of 3. This discrepancy is due to the finite trailer used in the simulations, which has been shorten-up in order to speed up the CPU-time.

CHARACTERIZATION OF IVUS

ALBA disposes of two identical In-Vacuum Undulators (IVU), located in Sectors S11 (NCD beamline) and S13 (Xaloc). In order to increase the sensitivity of the method, we have performed mode spectrum measurements scanning the gap of both IVUs at the same time.

In Fig. 6, we identify the IVU modes as a triple-peak around modes m_{IVU}=100, 130 and 170. The peaks are clearly visible for the minimum gap (5.7 mm) and gradually decrease until for 9 mm the peaks almost disappear in the general RW curve. Even though the transverse impedance is anti-symmetric in the frequency domain, note that no mirror peaks appear at $(h - m_{\text{IVU}})$. This surprising effect was already observed in Diamond [4] , and further investigations are still being carried out to understand this behaviour.

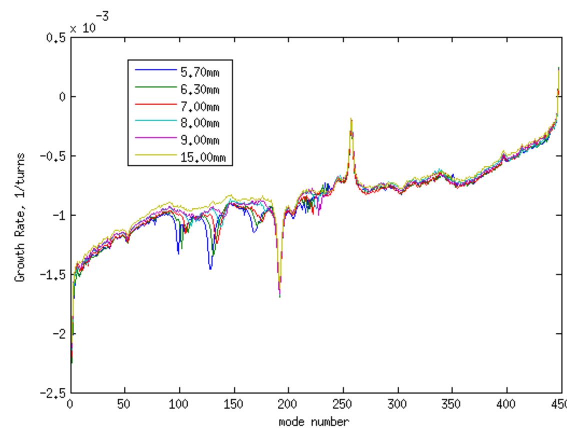

Figure 6: BBB mode spectra for different IVU gaps.

CONCLUSIONS

The transverse BBB feedback system is used to evaluate the growth rate of each of the multi-bunch modes at ALBA. This has been used to crosscheck the ALBA impedance model. It has been seen that the current RW-model shows some discrepancies with the measurements and further investigations are being carried out.

The narrow-band resonators have been identified as the vertical scraper and the in-vacuum undulators. While the peaks of the first one have been very well reproduced with ZAP simulations, the peaks of the IVUs are not well reproduced due to their non-symmetric behavior and further investigations are still being carried out.

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REFERENCES

[1] A. Olmos, U. Iriso, J. Moldes, F. Perez, M. Abbott, G. Rehm, I. Uzun, "Integration of the Diamond Transverse Multibunch Feedback System at ALBA", in *Proc. IBIC'15*, Mel-

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bourne, Australia, Sep. 2015, pp. 414–417. doi:10.18429/JACoW-IBIC2015-TUPB046

[2] A. Morgan, G. Rehm, and I. Uzun, “Performance and Features of the Diamond TMBF System”, in *Proc. EPAC’08*, Genoa, Italy, Jun. 2008, paper THPC126, pp. 3281–3283.

[3] G. Rehm, M.G. Abbott, A.F. Morgan, “New Features and Measurements using the Upgraded Transverse Multibunch Feedback at Diamond”, in *Proc. IBIC’14*, Monterey, CA, USA, Sep. 2014, paper WEPD24, pp. 696–699.

[4] R. Bartolini, R. Fielder, G. Rehm and V. Smaluk, “Analysis of Multi-bunch Instabilities at the Diamond Storage Ring”, in *Proc. IPAC’16*, Busan, Korea, May 2016, pp. 1685–1687. doi:10.18429/JACoW-IPAC2016-TUPOR013

[5] A. W. Chao, *Physics of Collective beam Instabilities in Accelerators*, New York, USA: Wiley, 1993.

[6] M. S. Zisman *et al.*, “ZAP User’s Manual”, LBL, Berkeley, USA, Rep. LBL-21270, 1986.

[7] T.Günzel and U. Iriso, “Revision of the Impedance Model for the Interpretation of the Single Bunch Measurements at ALBA”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, pp. 330–333. doi:10.18429/JACoW-IPAC2015-MOPJE026

[8] http://www.gdfidl.de