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LOCAL IMPEDANCE MEASUREMENTS USING THE ORBIT BUMP METHOD AT ALBA

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Abstract

The orbit bump technique has been implemented in the ALBA Storage Ring to characterize with good precision the impedance of single machine elements, like the in-vacuum undulators or the CLIC stripline kicker. The experimental results are compared with theoretical studies, as well as impedance measurements done at ALBA using other methods like the turn by turn betatron phase or the analysis of the detuning slopes of the Transverse Mode Coupling Instability (TMCI).

INTRODUCTION

Previous measurements of local impedance sources in the ALBA storage ring [1, 2] were based on the change of the TMCI detuning slope [1] and the fit of the betatron phase advance [2]. Both measurements showed some discrepancies between the experimental results and the modeled values for the In-Vacuum Undulators (IVU) [3].

It is very important to clarify as much as possible the real contribution of such elements to the total impedance budget because, on one side, IVUs with a small vertical gap are the major contributors to the total coupling impedance of modern synchrotron light sources and, on the other side, ALBA will increase the number of such devices in the following years.

The bump method described here has been already implemented in similar light sources, with significant agreement between measured and simulated kick factor values [4–6]. The aim of this paper is to achieve a better estimation of the real impedance of the ALBA IVUs with the bump technique, as well as to test its limitation with quite small impedance sources as the CLIC damping ring stripline extraction kicker [7].

BUMP METHOD

The local orbit bump technique was developed to measure the local transverse impedance in the VEPP-4M racetrack storage ring [4]. Later the same technique was applied in light sources as ELETTRA [5] and DIAMOND [6]. Equivalent methods involving closed bumps were implemented in the APS [8]. Recently, a faster version using AC bumps has been implemented in NSLS-II [9]. At ALBA, the hardware does not allow to implement an AC bump, hence the original DC technique has been used.

The measurements at ALBA were performed using as starting configuration a single bunch of 8 mA, with a small but not zero vertical chromaticity, which is just below the ALBA TMCI threshold (8.5 mA). An automatic script was used to apply the orbit bump, measure the orbit, scrape a fraction of the beam current, measure the orbit again and finally remove the orbit bump. The measurement of the orbit averages BPM data acquired during 30 seconds and the elapsed time between the two measurements is about 15-30 seconds depending on the required bunch current change. These values are taken as a compromise between accuracy (the longer the measurement the larger the effect of the natural beam current decay and the long term orbit drifts) and precision (the longer the measurement the better). The bunch current at the final configuration is varied from 7 to 3 mA.

In order to remove the BPM dependence on the bunch current, for each bunch current change, the orbit measurement is performed with two plane orbit bumps, at −1 mm and at +1 mm. Then for each bunch current change four orbits are stored, the high current high bump Y_{hchb}, the low current high bump Y_{lchb}, the high current low bump Y_{hclb} and the low current low bump Y_{lclb}. Each orbit difference measurement ΔY is defined as

$$\Delta Y = Y_{hchb} - Y_{lchb} - Y_{hclb} + Y_{lclb} \quad . \tag{1}$$

Each measurement consists of the 120 BPM vertical position readings. The orbit difference is used to fit the orbit kick ΔK at the location of the bump with a LOCO [10] fitted model of the storage ring obtained with a multibuch filling pattern and the IVUs closed. In this case we repeat this for different current changes ΔI to obtain the kick factor $\Delta K/\Delta I$.

Method Limitations

For low bunch current changes the beam current at the two configurations of the measurement is similar and hence its bunch length is also similar. Instead, for high bunch current changes the two states have quite different currents and hence different bunch lengths. This detail has not been included in the simulation which considers an average bunch length. This may effectively change the measured orbit change as a function of the beam current change and hence the measurement of the kick factor.

The obit bump produced leaks in its neighbouring elements (Fig. 1). In particular, in the case of the ALBA lattice, the beam at the adjacent dipoles moves around 10% of the bump at the intended location. There the beta function is roughly a factor 12 larger, so it could have a similar effect on the measurement if the effective impedance where similar. However, the dipole effective impedance is estimated to be 50 times smaller than the IVU and hence its effect should be negligible taking into account the present level of agreement.

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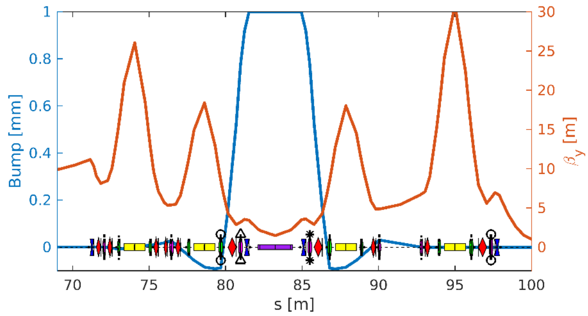

Figure 1: Orbit bump (blue line) of +1 mm at the impedance source location (purple block). A 10% of the bump (-100 μm) also affects the adjacent dipoles but the effect is negligible.

IMPEDANCE SIMULATIONS

As detailed in previous studies [1], the model contains two parts, the impedance of geometrical origin – also called broadband impedance – and impedance related mainly to the resistivity of the vacuum chamber walls – the wall impedance. The broadband impedance (BBI) is computed by simulation of electromagnetic wake fields in corresponding vacuum chambers with the program GdfidL [11], whereas the wall impedance is computed analytically.

RESULTS

The orbit bump method has been implemented at the two ALBA 21 mm period, 6 mm gap, 2 m long IVUs (producing light for the beamlines BL11 and BL13) and at the 20 mm gap, 1.7 m long CLIC stripline prototype installed at ALBA during last year. In all three cases the impedance sources are located in nearly identical 4 m long straight sections with a beta function of 1.22 m at the center.

The fit of the CLIC stripline kick factor $\Delta K/\Delta I$ is shown in Fig. 2. In this case the acquired data is quite close to the measurement accuracy limitation but still the measurement -33 ± 17 mrad m^{-1}A^{-1} makes sense and is in agreement with the expected value from simulations of -24 mrad m^{-1}A^{-1}.

In the case of the two, in principle, identical ALBA IVUs, the resulting kick factor is presented in Fig. 3. It agrees with the simulation -151 mrad m^{-1}A^{-1} in the case of BL11 -151 ± 4 mrad m^{-1}A^{-1}, but it does not in the case of BL13 -186 ± 21 mrad m^{-1}A^{-1}. A previous measurement of the BL13 IVU impedance with the betatron phase advance fit technique [2] and using a dedicated modified lattice with a factor 5 larger vertical beta function at the BL13 IVU location yielded a similar result -177 ± 6 mrad m^{-1}A^{-1}.

In this case, the linear fit seems not to pass through the zero orbit kick at zero bunch current change which may be caused by the above-mentioned method limitations. The overall orbit change fits seems quite good as illustrated in Fig. 4. After a careful analysis of the orbit change fit, we realized that there exists a non-fitted component which could be attributed (studied using the measured orbit response matrix) to an orbit kick in the neighborhood of the BL11

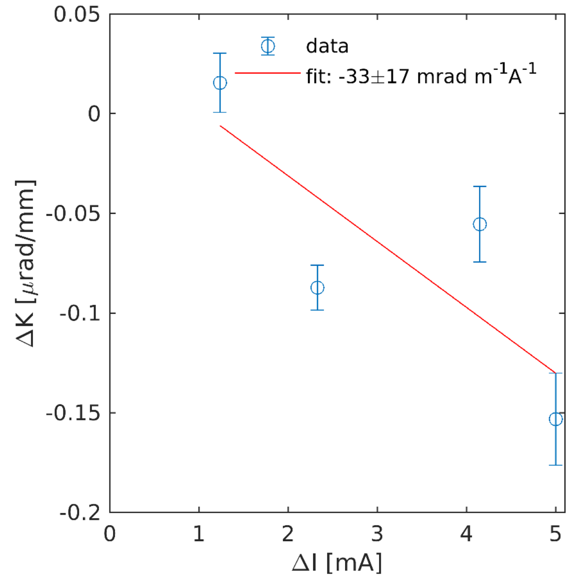

Figure 2: Fit of the measured transverse impedance kick factor $\Delta K/\Delta I$ using the bump method at the CLIC strip-line location.

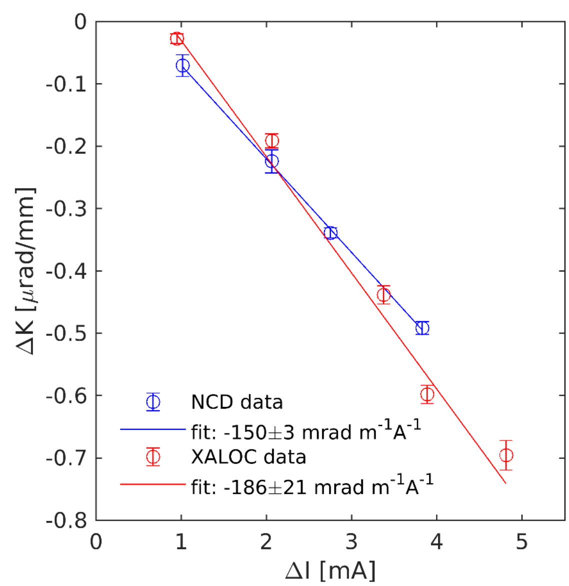

Figure 3: Fit of the measured transverse impedance kick factor using the bump method at the IVUs location.

IVU. This extra kick has a quite difference phase advance and is not produced immediately in the element but some meters apart. The origin of such impedance source is not clear, but in principle it should not have a major impact on the IVU impedance , since their effects on the orbit are quite decoupled. Interestingly enough in the case of the BL13 IVU, the non-fitted orbit change can also be attributed to an impedance near BL11 IVU. In any case, the fact that the linear fits shown in Fig. 3 do not seem compatible with the

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zero orbit kick at zero bunch current change is not understood yet.

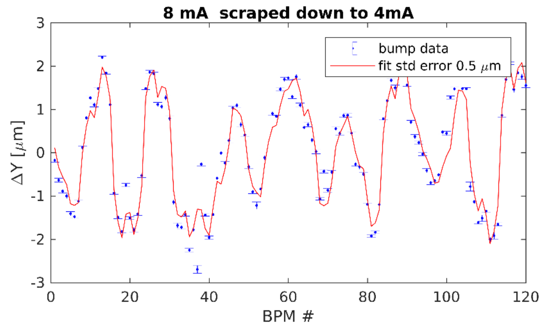

Figure 4: Orbit change ΔY fit in the case of BL11 and the largest current change from 8mA to 4mA.

Table 1 contains the measured and simulated kick factor results and the corresponding impedance in the case of the ALBA lattice.

It is worth pointing out that the obtained accuracy level is similar to the previous betatron phase fits [2], even if in that case a tuned optics with a beta function increased by a factor 5 was used to amplify the impedance kick factor effect. That technique also required a specific firmware for the BPMs electronics, not compatible with normal operation, that made that measurement technique quite complicated, at least for the ALBA case. The general agreement is quite good, except in the case of BL13 where the discrepancy reaches 25%, but agrees with the betatron phase fit result. The authors believe that this different behaviour could be explained if the beam was not centered at the BL13 location. We did tests measuring the beam losses in order to center the beam there, but the measurements resolution does not reach the necessary 1 mm level.

On the other hand the above-mentioned TMCI slope measurements showed a much larger impedance contribution at the IVUs. These measurements were taken for both BL11 and BL13 at the same time, and so the value in Table 1 corresponds to an average value of both IVUs. It is still not clear what could have caused such a big difference in the estimation of the effective impedance.

CONCLUSIONS

The local impedance measurement using orbit bumps has been implemented at ALBA. It yields results consistent with simulations except in the case of the BL13 undulator. It has not been clarified which is the cause of this large discrepancy. This method seems to be as precise as the previously used betatron phase fit which was more complex to implement and needed a tuned lattice with higher beta function value.

Table 1: Measured and simulated kick factors $\Delta K/\Delta I$ and equivalent effective impedance Z_{eff} for the ALBA IVUs and the CLIC stripline. Note that measurements using the TMCI slope were taken for both BL11 and BL13 at the same time.

device	$\Delta K/\Delta I$ [mrad m^{-1} A^{-1}]	Z_{eff} [kΩ/m]
	Betatron Phase	
IVU (BL13)	-177 ± 6	45.8 ± 1.6
	Orbit bump	
IVU (BL13)	-186 ± 21	48.1 ± 5.4
IVU (BL11)	-151 ± 4	39.1 ± 1.0
CLIC	-33 ± 17	8.5 ± 4.4
	TMCI slope	
IVU	-247	64
	Model	
IVU	-151	39
CLIC	-24	6.3

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