BEAM BASED CALIBRATION OF THE LNLS UVX STORAGE RING BPMS

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Abstract

The UVX electron storage ring at the Brazilian Synchrotron Light Laboratory (LNLS) was recently equipped with active current shunt circuits that allow for individual variation of the quadrupole magnet strengths. This allows us to apply the widely used technique of beam-based alignment (BBA) to calibrate the electrical center offset of the BPMs with respect to the magnetic center of the closest quadrupole. In this report we present the BBA experimental results and an analysis of the resolution of the method in the case of the LNLS UVX storage ring.

INTRODUCTION

LNLS UVX is a 1.37 GeV electron storage ring dedicated to the production of synchrotron light, located in Campinas, Brazil. The light source has been operating for users since 1997 and from the beginning improvements have continuously and gradually been implemented to enhance the storage ring performance. In 2007 a major survey and mechanical alignment procedure was performed on the storage ring girders supporting the magnetic elements in order to bring the strength of the orbit correctors to their original low levels. Over the years the horizontal correctors followed a slow drift and almost reached saturation. The next improvement regarding alignment was made possible in 2008 with the installation of individual active current shunt circuits in all 36 quadrupoles. The Beam Based Alignment technique could then be applied to calibrate the offset of the electrical center of the BPMs with respect to the magnetic center of the closest quadrupole. In this report we analyze the resolution of the method as applied to the LNLS storage ring. We also extended the method to calibrate a BPM with no quadrupole close to it. Finally, we show measured improvements in the beam quality obtained by correcting the beam orbit to the new reference, closer to the magnetic center of the quadrupoles.

THE BBA TECHNIQUE APPLIED AT LNLS

The BBA technique uses the stored beam as a probe to attain a better accuracy in the beam-to-quadrupole magnetic center alignment as compared to conventional alignment techniques based on fiducial reference marks. Whereas the conventional technique typically provides alignment errors of a few hundreds of microns, the beam-based techniques can in principle determine the position of the BPM centers with respect to the quadrupole magnetic center with an accuracy limited by the resolution of the BPM readings (a few microns) and by systematic errors related to the longitudinal distance between BPMs and quadrupoles.

A variety of BBA techniques have been applied in storage rings worldwide [1]. They are all based on the same principle, namely, to measure the orbit distortion caused by a change in the quadrupole strength as a function of the initial beam position at the quadrupole. When the beam passes through the center of the quadrupole no deflection in the orbit is produced. At this point of minimum orbit deflection the beam offset read by a BPM next to the quadrupole can be determined. The different implementations of this method are related to different ways of scanning the initial beam position at the quadrupole, either by a localized bump or by an orbit change all around the ring, and different ways to vary the quadrupole strength, either by switching between two excitation levels of the quadrupole or by exciting it harmonically at an appropriate frequency.

The method employed at LNLS uses only one corrector magnet to scan the initial orbit position at the quadrupole and a two-level step variation of the quadrupole strength. The orbit scanning corrector is chosen according to the plane of interest (horizontal or vertical) and the orbit displacement caused by it at the measured quadrupole. The quadrupole strength is varied by means of active shunt circuits and the amount of variation is set according to the best compromise between a small tune perturbation and a detectable effect on the decentralized orbit. As a result we use different shunt currents for quadrupoles at the long straights (3A) and at dispersive sections (1A).

The orbit variation due to the change in the quadrupole strength is characterized by a merit function χ, the sum of squares of orbit change at each BPM. The merit function χ is measured as a function of the nearest-to-the-quadrupole BPM reading and its minimum can be found by a simple parabolic fitting. Statistical errors in the BPM readings are minimized by averaging over many measurements. All measurement procedure is automated and care has been taken to ensure that acquisition timings are correct. The LNLS control system updates variable readings every $\approx$ 200 ms and the BPM readings are not synchronized. The power supplies also take some time to stabilize after a current change.

Since BBA is a zero detection technique, systematic errors related to the calibration of the strength of correctors and quadrupoles as well as those related to non-linear effects of the optics can be minimized by iterating the procedure. At each iteration the initial orbit position at the quadrupole is scanned in a region closer to the quadrupole magnetic center. As a standard we have applied two iterations for each BPM. The first iteration is a rough one with 5 points and large corrector span whereas the second iteration is a fine 11 points scan around the magnetic center of the quadrupole. Figure 1 shows a coarse and a fine orbit scan for the determination

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of the vertical offset of monitor AMP10A. The coarse scan is plotted against the corrector strength since the minimum gives directly the values for the corrector in the next scan. The fine scan, on the other hand, is plotted against the BPM reading since the minimum gives directly the BPM offset.

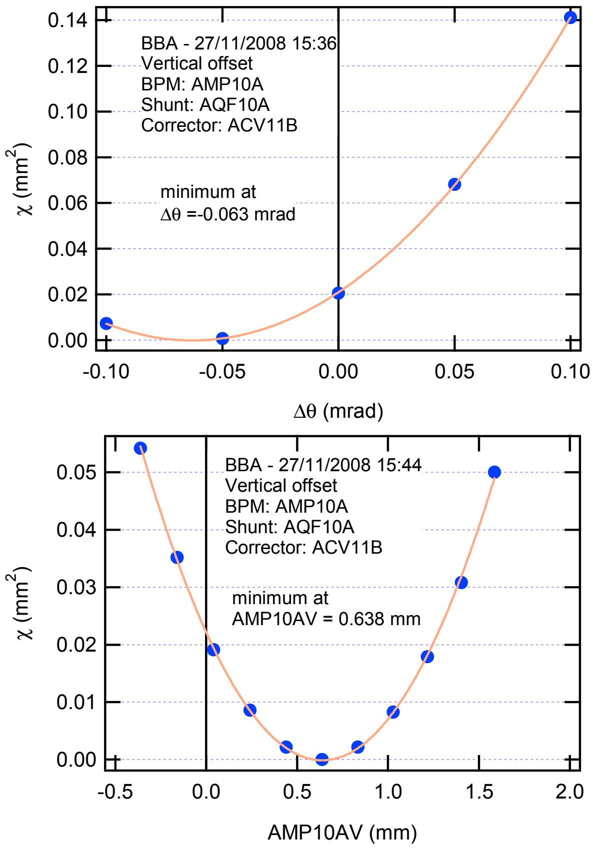

Figure 1: Coarse (top) and fine (bottom) iterations for BBA measurements to determine the vertical offset of BPM AMP10A.

At LNLS UVX most BPMs are located very close to quadrupoles. There are, however, some exceptions: (a) at the injection straight (a long dispersion free straight) a horizontal corrector is located between the monitor AMP03B and the nearest quadrupole, and (b) at the ondulator section two flanking BPMs (AMU11A/B) are located close to the extremities of the ondulator and somewhat distant from neighboring quadrupoles. See Figure 2. For case (a) we have turned the in-between corrector off and have set the operation mode with small betatron phase advance in the long straights. For case (b) the flanking BPM offsets can be obtained with the help of a third BPM (AMP11B), next to a quad, in the same straight section since there are no magnetic elements between the BPMs when the ondulator is opened. We first calibrate the reading of monitor AMP11B. Next we establish the orbit passing trough the center of the quadrupole AQF11A using the BBA technique (red curve in Figure 2. In this situation the offsets of BPMs AMU11A/B ($O_{A/B}$) can be easily calculated:

$$O_{A/B} = u_{A/B} - d_{A/B}\,\theta$$

where θ=z/d, and z, $u_{A/B}$ are respectively the readings of the calibrated monitor AMP11B and the uncalibrated monitors AMU11A/B.

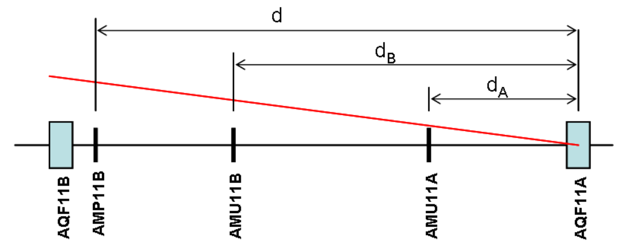

Figure 2: Schematic diagram of BPMs in the undulator section.

BBA RESULTS

Measurement Resolution and Repeatability

The precision and repeatability of the measured BPM offsets have been studied for various cases: for repeated measurements in the same lattice conditions (for the same and for different injected beams); for different lattice optics (with high and low betatron functions at the long straights); and for different correctors producing the orbit displacement at the quadrupole (in particular, we tested correctors creating the opposite orbit angle at the quadrupole crossing point).

In the case of close-to-quad BPMs, the variations in the measured offset for different cases are the same as the variations within the same case. For these BPMs the BBA offset measurements resulted in an rms variation of 25 μm. The same is not true for AMP03B, the BPM at injection straight which has a corrector separating it from the quadrupole. For this case the result obtained for different modes of operation, with high or low betatron function at the insertion straight, differ by 700 μm. Also the spread in offset due to measurements with different correctors is about four times bigger than for the close-to-quad BPMs. In the case of this BPM we take the average offset obtained from different correctors. This result demonstrates, as expected, that it is important to have a small phase advance between the BPM and the quadrupole.

Results

Table 1 presents the BBA calibration results obtained for the LNLS UVX BPMs. The offsets obtained show values up to a milimeter, if we exclude AMP03B, with a vertical misalignment of 2 mm as a result of being attached to the injection vacuum chamber. The offsets are a little bit above what we expected from the mechanical alignment procedure. We anticipate measuring some enhancement in the machine performance by making the beam to go through the centre of the magnetic elements. This is what we describe in the next section.

The estimated BBA accuracy of 25 µm is an order of magnitude higher than the BPM resolution of one micron. This can partially be explained by systematic errors induced by the small phase advance between BPMs and quadrupoles.

Table 1: BBA results for the LNLS UVX BPMs.

BPM	Hor. (mm)	Ver. (mm)	BPM	Hor. (mm)	Ver. (mm)
AMP01A	-0.332	0.417	AMP07A	-0.103	0.455
AMP01B	-0.037	0.063	AMP07B	0.569	0.189
AMP02A	0.723	0.458	AMP08A	-0.519	0.289
AMP02B	0.132	0.452	AMP08B	-0.340	0.315
AMP03A	0.472	0.140	AMP09A	-0.677	0.050
AMP03B	-0.949	2.070	AMP09B	0.261	0.432
AMP04A	-0.105	0.138	AMP10A	-0.530	0.638
AMP04B	0.009	0.918	AMP10B	0.127	0.445
AMP05A	0.450	0.355	AMU11A	0.110	0.771
AMP05B	-0.240	-0.186	AMU11B	-0.044	1.340
AMP06A	-0.756	1.837	AMP11B	0.145	0.296
AMP06B	-0.336	0.097	AMP12A	0.341	-0.085
			AMP12B	-0.072	-0.002

Machine Improvements

After calibration of horizontal and vertical offsets for all 25 BPMs in the LNLS UVX ring, a new golden orbit was defined, the offsetBBA orbit, that passes through the magnetic centres of the quadrupoles. We have performed a series of measurements to quantify the benefits of having the orbit corrected to the new offsetBBA reference as compared to the previous orbit, the zeroBPM orbit Figure 3 shows that the horizontal orbit distortion induced by a change in chromaticity, thus a change in all chromatic sextupoles, has decreased for the new orbit reference and Figure 4 shows an increase of approximately 30 minutes in beam lifetime.

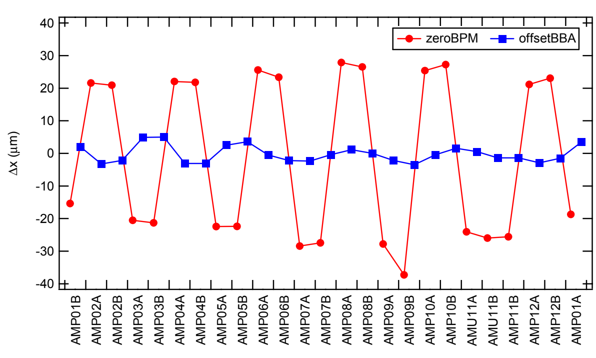

Figure 3: Horizontal orbit distortion induced by a variation in chromaticity for offsetBBA and zeroBPM orbit references.

Other measurements

As already mentioned, the BBA measurement implemented at LNLS is fully automated and, in addition, it is made easy to operate. As an example we point out an experiment performed by colleagues in the LNLS Diagnostics Group in which a series of BBA measurements was used to compare the drift in the offset of a new type of BPM as a function of beam current. The new BPM type, including refrigeration and a new kind of support, was installed in 1/3 of the ring by the end of 2008. It is supposed to drift less due to synchrotron radiation heating. The results in Figure 5 show indeed a reduction in the drift of the new BPM type.

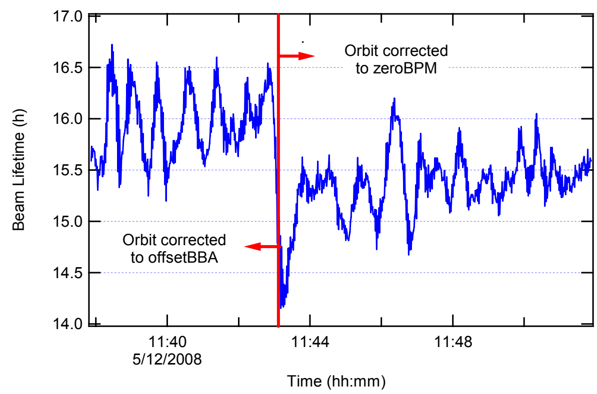

Figure 4: Decrease in beam lifetime by switching the reference orbit from offsetBBA to zeroBPM.

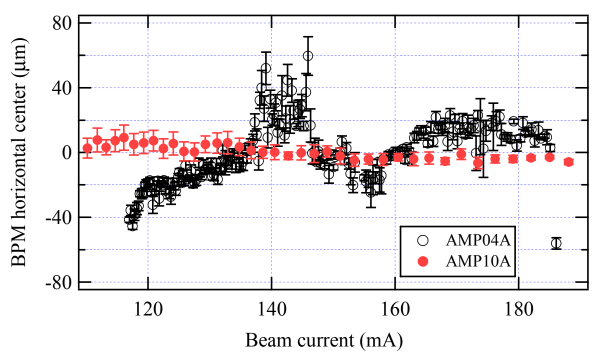

Figure 5: BBA measurements to compare the horizontal drift with current of a new type of button BPM (AMP10AH) with the old stripline type (AMP04AH).

CONCLUSIONS

The BBA technique has successfully been implemented at LNLS and has already been proved to be beneficial to the storage ring performance. With an easy to use interface available we expect to perform BBA calibration of the BPMs periodically.

We are grateful to the LNLS Diagnostics Group for providing the data on the new type of BPM characterization experiment.

REFERENCES

[1] See for example, J.Y.Huang et al, "Beam-Based Offset Calibration of the PLS BPM", PAC97; G.Portmann et al, "Automated Beam Based Alignment of the ALS Quadrupoles", PAC95, http://www.JACoW.org.